China Urban Transport Energy Activity Adaptation Potential Model:

An application of Transition Engineering methodology for Beijing's sustainable transport development

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Publications

Journal Papers

- Modelling Shopping Transport Energy Performance to Explore Low Carbon Potentials*, March 2016. Road and Transport Research.*
- Transition Engineering Analysis for Large Cities with Case Study of Private Work Access of Beijing. *International journal of sustainable transportation.(in progress)*

Peer-reviewed Conference Proceedings

- *Work Unit City: A Study of the Transport Design for Chinese Small City Urban Form,* presented at IPENZ TRANSPORTATION GROUP CONFERENCE 2015, New Zealand.
- *Modelling shopping transport energy performance to explore low carbon potentials,* presented at IPENZ TRANSPORTATION GROUP CONFERENCE 2016, New Zealand. (*This paper won the 'Best student paper' award with good reports and has been published in the journal of 'Road & Transport Research' as the invited paper*)
- *To phase out or preserve? The work unit design and its implications for sustainable and resilient urban development,* presented at Urban Transitions Global Summit 2016, Shanghai China.
- *Commuting distance and transport energy resilience—quantifying human commuting distribution to explore low carbon potentials with transition projects,* will be presented at IPENZ TRANSPORTATION GROUP CONFERENCE 2017, New Zealand.

Contents

Glossary of Terms

Transport activity: The movement of people or goods from one location to another. Based on the extent of individual freedom, human travel activities can be classified into two groups:

- **Rigid activities**: The activities that are hard to change in a relatively long time once the destinations are determined, such as work and education. These activities have to be participated in no matter what the conditions are.
- **Resilient activities**: The activities that are discretionary and relevant to mode choices, destinations, personal attributes and so forth, such as shopping and recreation.

Transition engineering: a new field and analytical tool for achieving a sustainable balance between risks and benefits of anthropological activity by innovating, designing and implementing changes in existing systems.

Urban form: The arrangement of functional units of a city, reflecting both the historical development of the city and its more recent planning history. The urban form can be represented by the spatial patterning of industrial, commercial and residential land uses and also by different levels of residential density.

Accessibility: the ability to access goods, services, activities, and destinations or "what, and how it can be reached, from a given point in space".

Adaptive capacity: the capacity of a traveller to adapt if the environment where he or she lives is changing. In urban transport energy systems, it can be regarded as the extent to which transport energy adaptations that are possibly realised without losing activity participation.

Work unit: a previously dominant urban form and basic social cell in China after 1949, following the principle of organising production and living in a spatial unit. Living in a work unit, each employee has access to basic needs such as work, shopping and education within walkable or cyclable distances.

Huff model: a spatial interaction model that computes the possibilities of consumers at a location patronising each shopping facility. As a gravity-based model, the Huff model is highly dependent on the shopping trip distance.

Essentiality: a metric to categorise transportation activities under the context of energy constraint, the essence of which is to decide whether trips represent an essential, necessary, or optional contribution to their well-being, socio-economic connection and happiness.

Shopping service value: The level of shopping prosperity of a shopping grid based on shopping scales and assigned essentialities.

Global shopping accessibility: The overall shopping accessibility to each shopping grid as a function of shopping frequency, shopping service value and possibilities.

Origin software: an industry-leading scientific graphing and data analysis software, providing a variety of tools for curve and surface fitting.

Baidu: a Chinese web services company offering many services including a Chinese search engine, audio files and images.

Baidu Huiyan: a business and geography data-based service from Baidu to capture customer profiles, trajectories and OD pairs.

Shopping aggregation: a metric to present the proportion of customers patronising a studied shopping area within a short distance (1km or 3km).

List of acronyms

CUTE AAP: China Urban Transport Energy Activity Adaptive Potential

AEMS Lab: Advanced Energy and Material Systems Lab

SACS: Strategic Analysis for Complex Systems

RECATS: Risk of Energy Constrained Activity-Transport Systems

META: Minimum Energy Transport Adaptability

AMA: Active Mode Accessibility

SATS: Strategic Analysis for Transport Systems

CBD: Central Business District

IEA: International Energy Agency

IMF: International Monetary Fund

OECD: Organisation for Economic Co-operation and Development

BJTRC: Beijing Transportation Research Centre

BJGHW: Beijing Municipal Commission of Urban Planning

NBS: National Bureau of Statistics, China

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Abstract

In response to climate change and fossil fuel shortages, many countries, including China, have committed to a clean and resilient economy and sustainable development. There are a variety of approaches to addressing energy issues ranging from technological improvement to policy adjustment. Although much attention has been paid to decarbonisation in terms of technological transformation, such as electric cars, renewable energy resources, vehicle emissions controls and so forth, the large scale implementation of these new technologies is still far away from reality. In order to deal with these tough issues, it is necessary to focus on reducing motor vehicle dependence in transport networks through urban redevelopment and travel behaviour change. Actually, China has a good foundation for achieving sustainable transport in terms of old urban forms and flexible non-motorised travel modes, which need to be re-examined to investigate its anti-risk ability and adaptive potentials to deal with a possible energy crisis.

Krumdieck has founded a new methodology called Transition Engineering for addressing wicked problems in complex systems. Following this way, the AEMS (Advanced Energy and Material Systems) Lab has already developed a series of metrics for measuring urban transport energy adaptation. Although these approaches have got fruitful deliverables in the context of New Zealand, there is no application of these approaches to the adaptation potential analysis of a metropolitan city, especially in the Chinese context. In view of the difference of national conditions, some Transition Engineering methods cannot be applied to Chinese cities directly, as they require modifications in some inputs and variables.

This study is the first trial to apply the methodology of Transition Engineering, with new contextualised metrics, to a specific city in China. After the introduction and reviews on background, literature and relevant methodologies, the model is elucidated in the successive chapters following the rationale of Transition Engineering. Through historical investigation, the work unit (Danwei) is found to be of interest for future sustainable development in China. However, due to the difficulty in obtaining detailed travel surveys of current travel patterns of Beijing, much effort was made to the travel activity modelling to characterise current transport energy performance. Analogous to the conventional work unit design, a new "urban village" with multifunctional land use for employment and shopping is proposed as the ideal model for a future car-free urban form in China after 100 years. Some new measurements for back-casting analysis are devised to find the most sustainable areas and most vulnerable areas for future development. Based on the strategic analysis tool, a quantitative activity adaptation model was developed and implemented in a GIS-enabled computer program in order to analyse transport adaptive capacity in the current urban form, and also as a result of re-development options in the urban environment. The approaches are applied in two case studies on Beijing with six different scenarios to compare their relative merits. After comparison, the best opportunity for shift project is proposed as either the 'electric bike penetration' development or the new "urban village" housing development form with cycle path enhancements and government support of electric cycle ownership. This research demonstrates the new Transition Engineering approach to sustainable development that results in actionable property and infrastructure development with financial and social benefits which are clearly communicated to all stakeholders.

1. Introduction

1.1 Background

Transport networks are fundamental to urban function as access to goods, services and activities, and the transport system is a prerequisite condition for economic prosperity and the well-being of local residents. However, with the development of transport networks, there have been serious sustainability issues that impair human health and the environment. According to the Union of Concerned Scientists (2014), transportation is the largest source of air pollution in the United States. It is estimated that road transport is responsible for 23% of total greenhouse gas emissions (IPCC, 2007). In addition, the combined spending on building and repairing roads, parking, signals, policing, and traffic accident response is typically one of the largest expenses for any city (BUHL et al., 2004; 2013). Furthermore, these costs are likely to continue to rise with the ageing of infrastructure and the sprawling tendency in urban development. Transport poverty has become an issue where cities become segregated and lower income people are forced to live in areas outside of the city, often with the cost of transport limiting their access to jobs and services (Hine, 2004). The scale of urban areas and the disruption to human scale caused by massive freeways have been identified as quality of life issues in cities (Robert, 2006). Moreover, owing to the peak oil risks and unstable price of petroleum, the need to keep the balance of energy supply-demand has become even more urgent.

Although renewable transport energy, such as biofuels and electric vehicles, has been a promising research direction for energy conservation and mitigating greenhouse gas emissions, the feasibility of renewable energy transport is still far from reality on account of the difficulties in technical breakthroughs, commercialisation and popularisation. Noticeably, it is argued that the active mode of transport, walking and cycling, are the most sustainable transport modes (Tolley, 2003). An urban form with high-level active modes would contribute to sustainable transport. Urban form is a general term encompassing the land use pattern, locations of buildings, and the transportation infrastructure. Changes in urban form have direct impacts on transport networks and vice versa.

The state of the art in transport network modelling is the conventional 4-steps transport forecasting model widely used in the industry (Ortúzar et al., 2001). It is used to estimate transport performance (e.g. traffic volumes, travel times), financial viability of infrastructure and environmental impacts (Meyer& Miller, 1984). Starting with the collection of current traffic data, the travel demand model has been developed and combined with other socioeconomic data, such as demography, employment, travel costs and so forth. With the assistance of computer modelling, traffic forecasts are widely used in the field of urban design, transport planning and policy to estimate the capacity, feasibility and impact of projects. The 4-steps model is an idealistic, rational framework to determine the travel demand, which comprises 4 sequential steps: Trip Generation, Trip Distribution, Mode Choice and Trip Assignment. By analysing the socioeconomic factors in one region, a number of trips are generated and subsequently distributed between origins and destinations. Based on the proportion of transportation mode choices, the distributed trips are allocated into the transport networks for evaluation according to certain criteria and metrics. The activity-based model predicts where and when individuals perform specific activities assuming that travel demand is from activities people want to perform.

However, there are some imperfect aspects in transport forecasting modelling, such as its aggregate nature, accuracy issues (Shoup, 2003) and viability issues in practice. In addition, transport models are also very seldom validated with data.

1.2 Motivation

1.2.1 Peak oil

In 1998 the *Scientific American* paper by petroleum geologist, Joseph Campbell, described the peak and decline of world oil production from conventional, low-cost reserves. Current urban transportation in all modern cities is completely dependent on oil, so we would expect an upsurge in research looking at the vulnerability of transportation activity systems to declining oil supply (Robert, 2011). However, this area of sustainable transport research is still relatively new and the papers listed in Table 1-1 are the results of the key word search "peak oil" in the leading transport journals.

Table 0-1 Peak Oil Reviews

Study	Location	Results
Whipple (2008)	U.S.A. and world major oil exporters	• Production of crude oil has basically been flat since 2005. • The reduction in oil production will stretch over decades or more, and likely over centuries. • The major oil exporters are using more and more of their own oil domestically, so there is less available to sell.
Graefe (2009)	Global energy outlook	• The "easy" conventional oil that the world relies upon as a primary energy source is being depleted • The world has to face the challenge of adapting to a new model of energy supply • The transition from conventional oil to substitutes will be expensive and chaotic • It is possible to focus on discovering the best way to transition to a world with less conventional oil
Hopkins (2012)	U.K.	The future will be more localised, more nourishing, and will need to shift the focus from sustainability to resilience. Transition movement supporting communities setting up their own energy companies, local currencies, food systems, etc.

		is a new bottom-up approach to economic development when oil extraction declines.
Kerr (2011)	Non-OPEC oil producing countries	• Non-OPEC oil production may have peaked. • Unconventional oil is in abundance but hard to extract.

1.2.2 Oil predicament in China

Under the ‘reform and opening-up’ policy starting from 1978, China has been dedicated to economic development and national modernisation. As the most populous country in the world, China recently became the second largest economy and is increasingly playing an important and influential role in the global economy (The World Bank, 2014). However, with rapid economic growth and strong ambition for modernisation, the demand from China for world energy is increasing, and recently it surpassed that of the USA. In 1993, China became a net oil-importing country, with more than half of oil consumption in China from imports; this trend is likely to continue in the future (Figure 1-1). The increasing reliance on the world energy supply represents a new threat to China’s national security and economic growth in view of the uncertainty of import costs and the geopolitical risks from primary oil exporters in the Middle East (Zhang, Ji, & Fan, 2013), and also it has significant influences on the world economy and politics. The whole world’s resources would not meet the giant and growing demand from China if it continues such extensive development. Accordingly, it is imperative for China to find alternatives to reduce the gap between energy demand and energy production in the course of economic development.

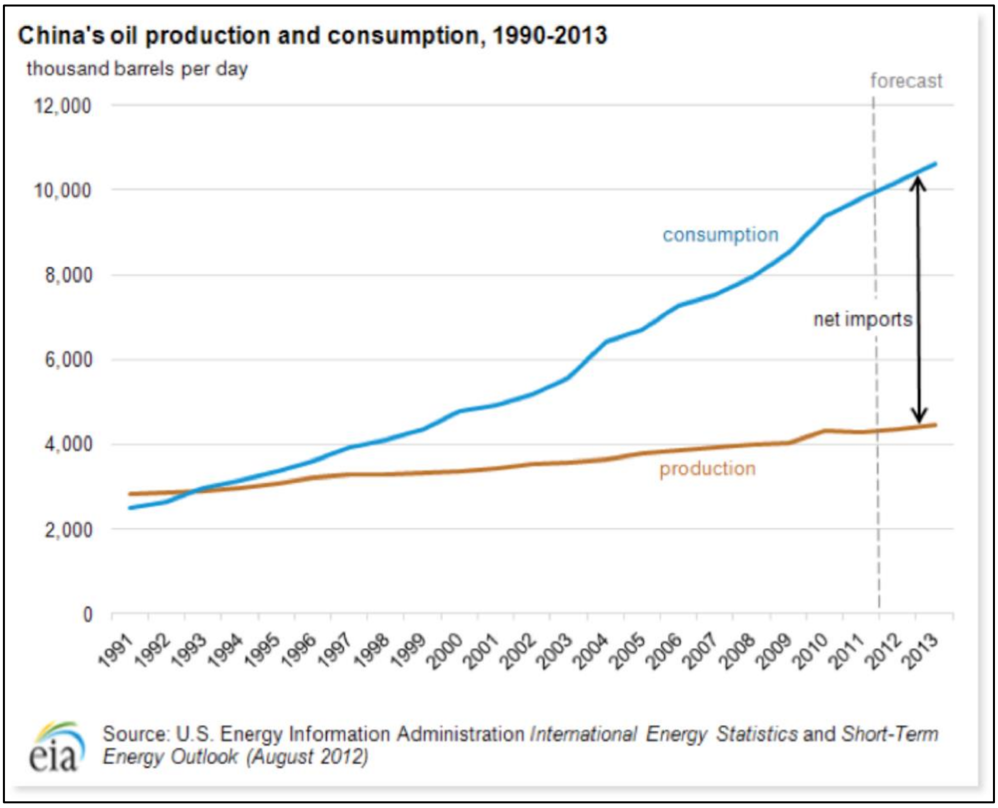


Figure 1-1 The gap between oil production and consumption in China

Admittedly, the Chinese government is now changing its ideas about its long-term economic and energy development strategies. In fact, the Chinese government has realised the importance of sustainable development taking into account the variance in oil price and the restraint on oil demand. Also, the significance of sustainability is highlighted in China's Five Year Plan (FYP). Elspeth (2014) pointed out that the 12th FYP could be seen as the greenest FYP in China's history as it attaches more importance to development, such as energy efficient technologies and reducing emissions rather than pure growth. While the Chinese government calls for the state-owned economy in key energy areas to maintain its leading role, it also loosens the restrictions on private investment and financing in the energy sector.

Although the considerable emphasis on sustainability with more renewable energy and green technologies has been integrated into development plans for China, it is believed that the majority of countries are still far from achieving fully sustainable energy systems (WEC, 2012). For China, the issues involving transport energy are particularly acute due to the resource availability problem. There is not enough space for transport infrastructure to accommodate a large vehicle fleet. The negative impacts of massive motorisation in China, such as traffic congestion and air pollution will be even more serious if the dependence on motor vehicles is not effectively controlled (Kenworthy & Hu, 2002). In response to these tough issues, it is necessary to focus on reducing motor vehicle dependence in transport networks through urban redevelopment and travel behaviour change. In fact, China has a good basis for achieving sustainable transport in terms of traditional urban form (the work unit) and flexible non-motorised travel modes, such as the bicycle and electric bikes, which need to be re-examined to investigate their anti-risk ability and adaptive potentials to deal with a possible energy crisis.

1.3 Problem statement

The objective of this research is to characterise the energy transport activity adaptive capacity and evaluate the potential for transport energy transition projects based on a new perspective, Transition Engineering methodology, with the attempt to reduce the conventional motor vehicle dependence in urban transport systems through physical environment redevelopment and human travel pattern changes. A model framework called 'China Urban Transport Energy Activity Adaptation Potential Model' (CUTEAAP) is developed in this research, with which the historical development of urban form and transport system, current travel patterns and the ability to adapt to possible petrol car constraints are to be analysed.

1.4 Contribution of the study

Unlike conventional transportation models, this research presents a new approach to analysing urban sustainable development potentials from the perspective of travel behaviour change with development scenarios in land use and transport systems. Although a new methodology called Transition Engineering was founded by Krumdieck (2012), the practical application of relevant methods in a specific city is still relatively new, especially in the Chinese context. The RECATS model has proposed an ‘essentiality theory’ to categorise the importance of human travel activities to their well-being and happiness. Following this way, a refined shopping activity model on the combination of the Huff model and the ‘essentiality theory’ was developed to characterise human shopping transport energy performance, thereby facilitating the subsequent low carbon potentials exploration. The META model calculates the minimum transport energy consumption based on the impedance of viable travel time by an alternative low energy travel mode; however, the current transport energy patterns and the opportunity as to how to transition from the existing system are not involved in this model. Having studied some sample data, a new commute model based on the trip distance distribution was developed to characterise present commuting activities. Given a small travel survey in sample areas, the proportion of commuters in a certain distance bin can be calculated for any study region, laying a foundation for the following adaptation analysis. Consequently, this model is of practical use for city planners and transport engineers to estimate the trip distribution with fewer data requirements.

1.5 Scope and limitation of this research

Instead of providing forecasts for future changes, this research is a diagnostic tool to examine the potential for low energy intensity trips in a city. The research area of this study is mainly focused on the civil transportation within Beijing city. Our research is limited to:

- Household-based one-way trip. All the models were based on the assumption that a trip starts from home and ends at a facility.
- Tangible variables that can be measured or quantified such as distance, population, and area. Unlike the traditional transportation model accounting for the economic and psychological dimensions of trip activities, this research is focused on GIS data, the physical environment and geographical location only.
- In our research, the adaptive ability to active mode travel, that is, walking and cycling (including the electric-bike), is the primary indicator of the risk of unsustainable development in a city.
- Due to the limitation of data availability, only work and shopping trips are selected as the representative of rigid travel activities (work and education) and elastic travel activities (shopping, recreation, and hospitality) respectively. In fact, work and shopping trips in Beijing account for nearly 75% of all trips. Therefore, the selection of work and shopping trips is appropriate for this study.
- It is assumed that car driving reduction in work trips cannot affect the economy but they can have a negative impact on personal well-being, such as longer travel times, safety issues, and home relocation. By contrast, the

reduction in shopping car trips would have an impact on economic activity participation, such as decreased trip frequency to distant shops, and other destination choices.

The following aspects are excluded:

- Freight travel
- Inter-city activities
- Transit trips
- Rural travel
- Trip-chaining and trip legs

The administrative division of Beijing at the district level is shown in Figure 1-2, with the respective function of each district being presented.

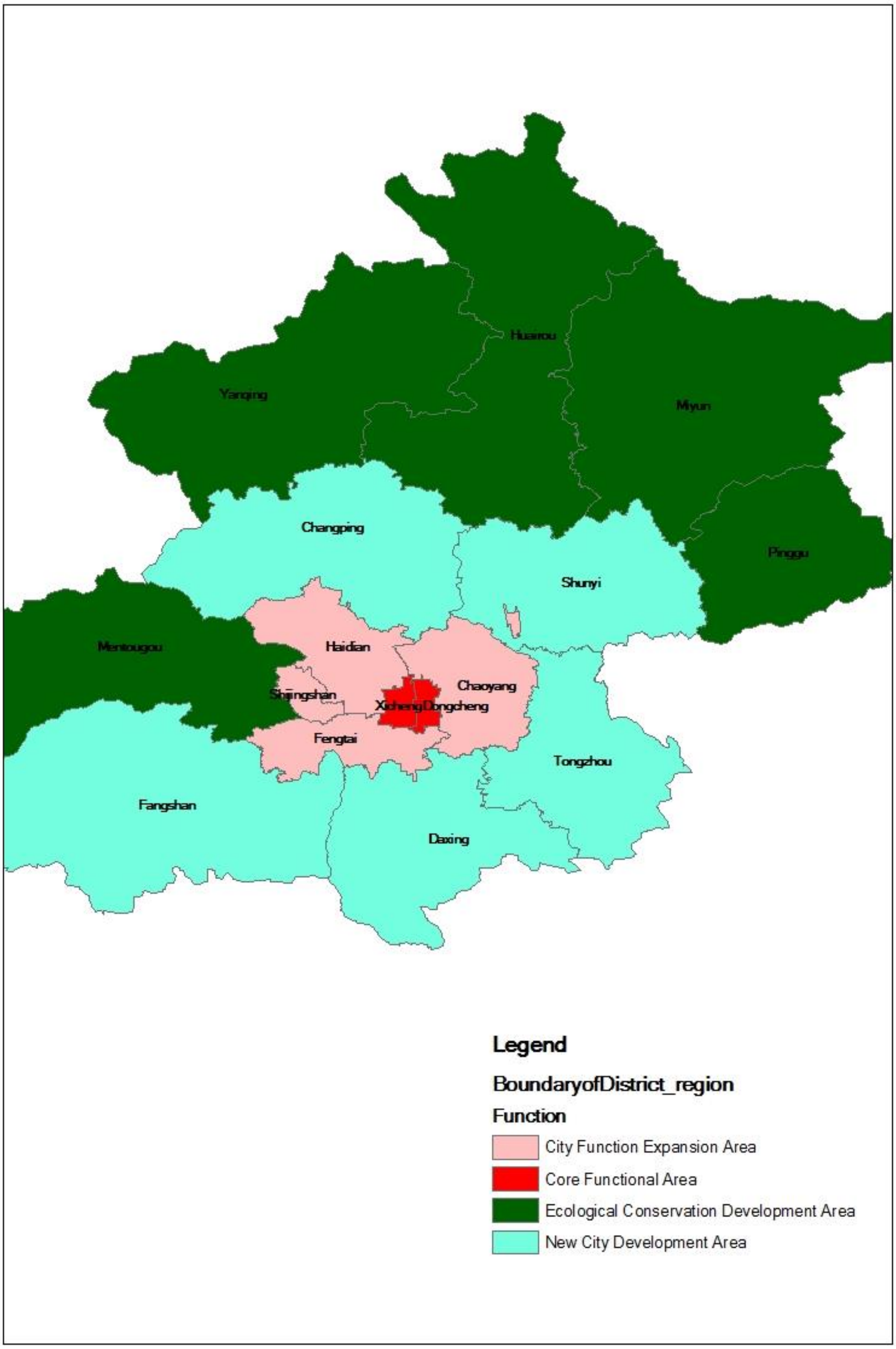


Figure 1-2 The administrative division of Beijing

1.6 Organisation of thesis

This thesis is an application of Transition Engineering to a specific city in China, with some simplifications and necessary modifications in some inputs and variables. The first four chapters cover the basic conceptions about an integrated urban transport system and the theoretical foundations for human mobility, travel activity modelling and adaptation modelling. The remaining chapters are a detailed description of the CUTEAAP model following the steps of the Transition Engineering framework.

Chapter 2: reviews the basic conception of urban form development, transport planning and accessibility; it examines the interaction between urban form and the transport system, and discusses the existing studies on how to reduce transport energy use in terms of urban form changes, transport technology transformation as well as the implications of mode shift to walking and cycling.

Chapter 3: presents the state of art in unravelling human mobility laws, modelling shopping activities and work trips and analysing human adaptive capacity in energy and resource constraints.

Chapter 4: provides a brief introduction to the methods that will be used in this research, including data collection and analysis, travel activity modelling and several analysis tools.

Chapter 5: is a historical investigation on Chinese urban form and transport systems after 1949. A previously dominant urban form——The Work Unit (Danwei) is paid more attention in this chapter on account of its significance for future sustainable development.

Chapter 6: presents the approaches for characterising current transport energy performance with a focus on shopping and work trips only. These metrics and models can be employed as alternatives to learn about human travel distributions in different distance bins, meanwhile laying a convenient mathematical foundation for the following adaptation analysis.

Chapter 7: discusses some possible future scenarios that might imply unsustainable risks according to current development tendencies in China, including options of urban sprawl, fuel economy and electric cars.

Chapter 8: demonstrates the path-break vision after 100 years, when no fossil fuels are available. Based on the prototype of the traditional work unit form, the "new urban village" lifestyle is envisioned to be the typical urban form in the future.

Chapter 9: presents a back-casting analysis with developed metrics to compare the differences between the future vision and the present situation. With the assistance of GIS techniques, the most resilient areas and the most vulnerable areas can be identified through back-casting approaches.

Chapter 10: proposes several analysis tools for transition development in the context of trigger events, with two case studies in the city centre and suburban areas of Beijing. The modified model of strategic analysis for complex systems is further expanded and a cycling-oriented adaptation model is developed in this chapter. The transition projects with a work unit design are illustrated at the end of these two case studies.

Chapter 11: validates the developed shopping model with empirical data derived from Big Data survey, and the developed commute model with the VKT data from New Zealand.

Chapter 12: concludes with the significance of Transition Engineering for Chinese sustainable development.

2. Review of relevant literature

This chapter reviews the history of urban form development, examines the basic conceptions about transport planning, then investigates the interactive mechanism between land use and the transport system. The studies on how to measure accessibility are also included due to their significance in modelling travel activities. Finally, cutting edge research on how to reduce transport energy consumption is discussed with respect to urban form changes, technological transformation in the transport system and the mode choices for walking and cycling.

2.1 Urban form development

Urban form is defined by Rose (1967) as the arrangement of the larger functional units of a city, reflecting both the historical development of the city and its more recent planning history; it is represented by the spatial pattern of industrial, commercial and residential land uses and also by different levels of residential density. A history of cities illuminates the driving force to shape the nature of cities. According to Newman & Kenworthy (1999), the evolvement of a city follows a historical route:

The walking city →The transit city →The automobile city

With the progress in transportation technology and the growth in population, as well as the development of cultural and economic factors, city areas are becoming wider with more diversified facilities attracting more people to visit. Especially with the advent of the automobile, people can travel faster within their time budget, making it possible for them to live further from their destinations. At present, many cities in developed countries have developed as almost exclusively auto cities; by contrast, cities in the third world are still on the way to becoming auto cities although most of them have automobile-oriented traffic development patterns.

Besides the classification based on the dominant transportation means, there are some other methods to define the urban form. Newton (2000) summarised the key alternative urban forms or ‘archetypal urban geometries’, such as the dispersed city, the compact city, the edge city, the corridor city, and the fringe city. For example, Hong Kong and Singapore are classic compact cities with high density and highly mixed land uses.

2.2 Transport planning

Transport planning is the measure as to how to lay out land use and provide related facilities to meet future transportation requirements. It aims at the design of an efficient infrastructure and service to efficiently move people and goods (Goulias et al., 2003, 2002). Transport planning is an integral part of shaping cities, boosting economic activities, promoting social interactions and improving the quality of life. A good understanding of human behaviour is a key component for well-designed transport systems.

The most popular methodology in addressing urban transport problems is the classical transport demand model based on the 4-steps modelling procedure (Hensher & Button, 2008). Starting with the collection of current traffic data, the travel demand model has been developed, which combines other socioeconomic data such as demography, employment, travel costs and so forth. With the assistance of computer modelling, traffic forecasts are widely used in the field of urban design, transport planning and policy to estimate the capacity, feasibility and impact of projects. The 4-steps model is an idealistic rational framework to determine the travel demand, which is comprised of four sequential steps: Trip Generation, Trip Distribution, Mode Choice and Trip Assignment. By analysing the socioeconomic factors in one region, a number of trips are generated and subsequently distributed between origins and destinations. Based on the proportion of transportation mode choices, the distributed trips are allocated into the transport networks for evaluation according to certain criteria and metrics. In addition, the activity-based model is emerging as a disaggregated way to predict where and when individuals perform specific activities assuming that travel demand is from activities people want to perform. There are some imperfect aspects in transport forecasting modelling, such as its aggregate nature, accuracy issues (Shoup, 2003) and viability issues in practice. Transport models are also very seldom validated with empirical data. Also, the automobile-based travel model is not effective for low carbon design in consideration of active modes like walking and cycling (Kuzmyak, Baber, & Savory, 2006).

2.3 Interactive mechanism between land use and transportation

Land use refers to the situation and methods on how to use urban land; the attributes of land use include land function, land scale, spatial morphology and structure. The land function can be classified as habitat, public service, industry, business, and transport infrastructure. The spatial morphology and structure reflect the proportion of land functions as well as their layout. Different land functions, layout and development intensity lead to different travel demands. Meanwhile, the development of transport can induce changes in land use. The relationship between land use and transportation is a complicated dynamic process with interactive effects. State of the art analysis of the relationship between urban form and transportation networks and travel demand is centred on the built environment impact variables and transport variables, in association with socioeconomic factors, which can be simplified (see Figure 2-1). Basically, land use and transport are mutually intertwined. Changes in transport systems could affect urban development and location choices of households and enterprises, and the changes in land use could influence the number of trips and mode choices (Paul, 2014).

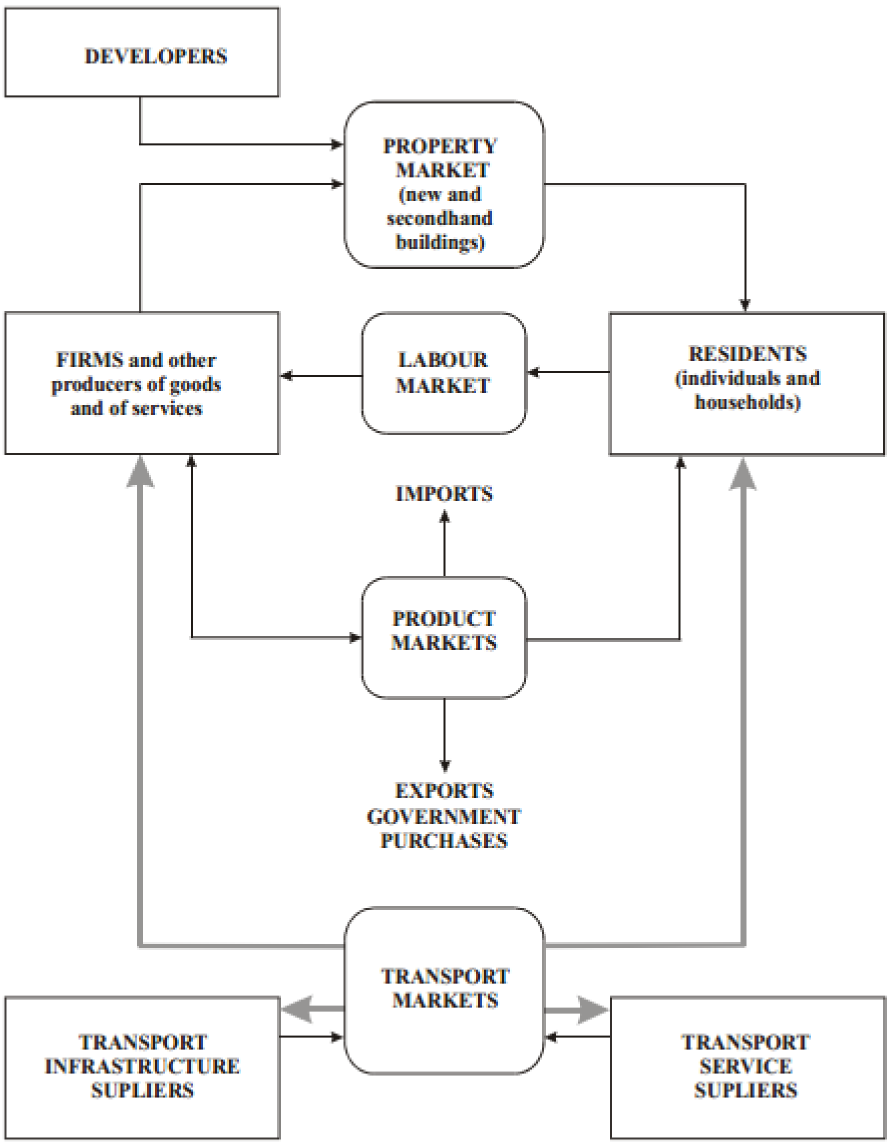


Figure 2-1 Actors and Markets in Land-Use/Transport Interaction Models (Department for Transport, U.K, 2014)

Understanding the interactions between land-use and transport is the core task of the development of cities and regions. Many models of Land-Use Transport Interaction (LUTI) were developed and mainly used on strategic scales. The first attempt to explore the land use and transport feedback cycle was implemented by Lowry (1964). The essential thought of the Lowry model is to link two interrelated components represented by a residential location model and an employment and service location model. Employment and service are divided into basic sectors (e.g. industry, government, and company) and non-basic sectors (e.g. retail, and entertainment). The basic sectors are exogenous variables as the given input, and the non-basic sectors sell goods and services to locals, which are endogenous variables determined by models. Residence sectors include employees from basic and non-basic sectors. The flowchart of the Lowry model is shown in Figure 2-2. The development forecast is given by a regional economic growth model; the size of the residential area is determined by employment opportunities and the location is determined by accessibility to employment; and the size and location of retail sectors are determined by the size and location of the residence. The Lowry model is a classic comprehensive land use-transport model to simulate a number of complex modelling approaches, such as the work done by Goldner (1971), Geralder et al. (1978), and Mackett (1983).

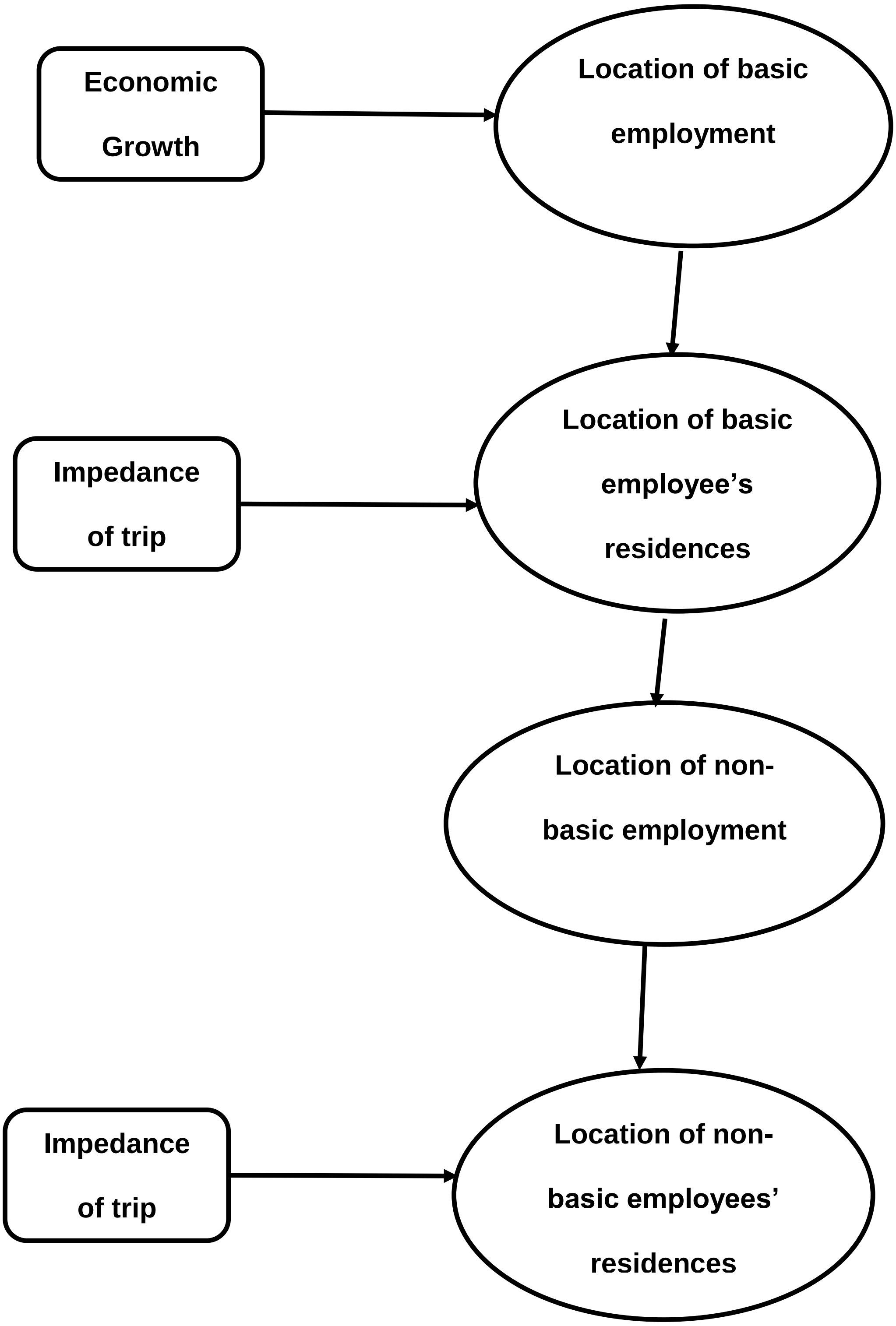


Figure 2-2 Flowchart of Lowry model

Nevertheless, the transport network capacity cannot be extended infinitely due to space limitations, typically because of the use of the automobile. When the land uses are changed to some extent, the ensuing traffic flow will increase congestion, and, in turn, decrease the level of accessibility (see Fig 2-3, Handy, 1993). If there is no space available to accommodate more traffic flow, the accessibility to this area might decrease, consequently deteriorating the development in this area.

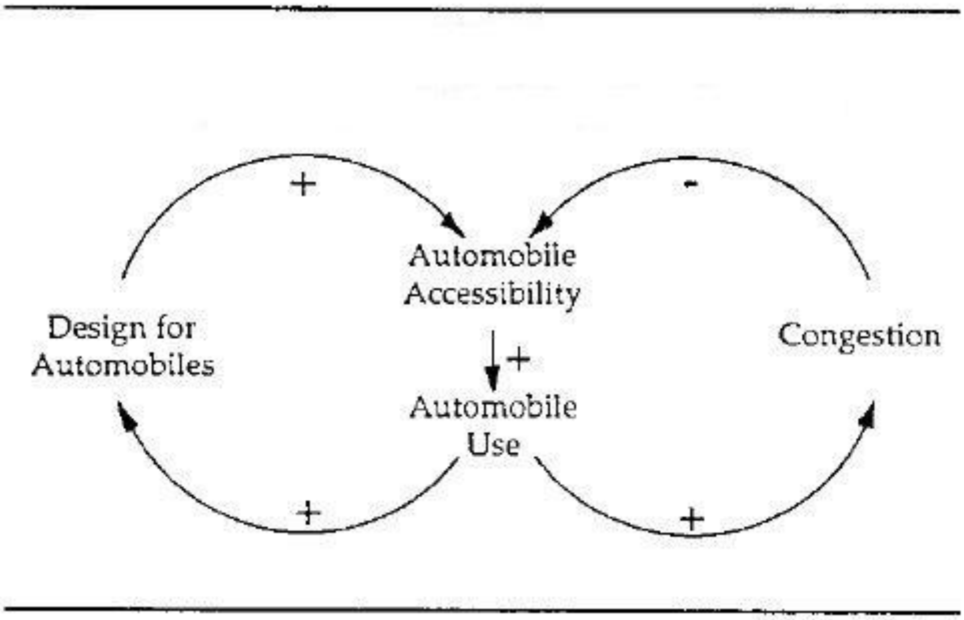


Figure 2-3 The cycle of dependence—The cycle of destruction

Litman (2015) pointed out that the incremental growth in road construction and parking supply create more dispersed land use patterns, increasing the travel distances required to access given destinations. He made a comparison between smart growth and sprawl development to see how transport planning decisions affect land use. He argued that the policies that reduce the generalised cost (e.g. financial cost, travel time, discomfort, and risk) of car trips tend to increase traffic and sprawl;

in contrast, the encouragement of non-motorised travel and the improvement in transit system are beneficial to smart growth (see Table 2-1).

Table 2-1 Transport policy land use impacts

Sprawl development	Smart growth
Increased roadway capacity and speeds	Reduced roadway capacity and speeds
Generous parking requirements	Reduced parking supply
Free or subsidised parking	Parking pricing and management
Low vehicle operating fees	Road pricing and distance-based vehicle fees
Worse public transport service	Better public transport service and improvement in transit infrastructure
Poor walking and cycling conditions	Pedestrian and cycling improvements

2.4 Accessibility

Accessibility is defined as the ability to access goods, services, activities, and destinations or “what, and how can it be reached, from a given point in space” (Bertolini et al., 2005; Yigitcanlar et al., 2007). Accessibility is a continuous variable, which is measured by counting the number of activities (e.g. jobs) available at a given distance from an origin (e.g. the home), and discounting that number by the intervening travel time (Hansen, 1959). At present, accessibility is gradually becoming a good metric to evaluate urban transportation systems. A comparative study on the accessibility measures conducted by Makri and Folkesson (1999) is summarised as follows:

Distance-based measures. The simplest way to measure accessibility is by counting the distance from one origin to different destinations: the closer the destination the higher the accessibility. The attraction of the destination, however, is not included in this measure.

Cumulative-opportunity measures. The accessibility is defined by the number or proportion of opportunities accessible within a certain travel distance or time range from an origin. However, the heterogeneity of each destination is not considered in these measures; in other words, all the potential opportunities within the specified area are equally weighted.

Gravity-based measures. This method, which is analogous to Newton's Law of Gravity in physics, was first proposed by Hanson (1959) and then has been widely used in the transportation field. The basic form of the gravity-based accessibility is expressed as:

$$A_i = \frac{\sum_j a_j * f(d_{ij})}{A} \qquad (2\text{-}1)$$

where a_j is the attraction in zone *j*, d_{ij} is the travel impedance between *i* and *j*, $\mathrm{f}(d_{ij})$ is the impedance function, and A is the normalising factor. A_i is the overall accessibility for zone *i*. The most commonly used variable of the impedance function is the inverse power function d_{ij}^{-x}.

Utility-based measures. Based on the random utility theory, assuming that the individual gives each destination a utility value, the possibility of an individual choosing a destination is the quotient of the utility of that choice compared to the overall utility of all choices, as follows:

$$A_c = \frac{e^{V_c}}{\sum_{c \in C_n} e^{V_c}} \qquad (2\text{-}2)$$

where V_c is the utility value of destination C, and C_n is the choice set of destinations. The values of various parameters are determined after calibration.

Geurs and Wee (2004) presented a review of accessibility measures in evaluating land use and transport strategies. In this literature review, accessibility measures were reviewed in accordance with a range of relevant criteria including theoretical basis, interoperability, data requirements and usability in socioeconomic evaluations. A number of components of accessibility are identified, and, consequently, four perspectives on measuring accessibility are determined, which are a matrix of perspectives on accessibility and components as listed in the following table (Table 2-2):

Table 2-2 Perspectives on accessibility and components

Measure	**Component**			
	Transport component	*Land use component*	*Temporal component*	*Individual component*
Infrastructure-based	Travelling speed; vehicle hours lost in congestion		Peak-hour period; 24-h period	Trip-based stratification, e.g. home-to-work, business
Location-based	Travel time and/or costs between locations of activities	Amount and spatial distribution of the demand for and/or supply of opportunities	Travel time and costs may differ, e.g. between hours of the day, between days of the week, or seasons	Stratification of the population (e.g. by income, educational level)

Person-based	Travel time between locations of activities	Amount and spatial distribution of supplied opportunities	Temporal constraints for activities and time available for activities	Accessibility is analysed at individual level
Utility-based	Travel costs between locations of activities	Amount and spatial distribution of supplied opportunities	Amount and spatial distribution of supplied opportunities	Utility is derived from the individual or homogeneous population group level

The author argued that a good accessibility measure should be sensitive to changes in the quality of transport services, the amount and distribution of the supply and demand for opportunities, as well as temporal constraints; the human factors, including individual needs, preference and competency are also indispensable in the analysis.

Rendall et al. (2011) developed an active mode accessibility (AMA) measure to quantify transport energy resilience of households to fuel shocks, which is characterised by the underlying geographic form of an urban area and related transport networks. Active mode accessibility is defined as the proportion of activities that can be reached by human-powered transportation (such as walking, running and cycling). It is obvious that AMA is negatively related to oil use: an urban transportation system with higher AMA could potentially be less reliant on oil for transportation. Generally, for the central city, the accessibility is very high on account of its convenient connectivity and densely distributed facilities.

2.5 Transport energy reduction

In general, there are three approaches to reducing transport energy consumption: the development of technical innovation (e.g. new energy vehicles and new materials); the enforcement of social management policy (e.g. pricing system, transportation rule and education); and integrated urban planning (Saunders et al., 2008).

The transport energy consumption of an individual is a product of the transportation modes used, distances to selected destinations, and the activity frequency, which are in turn dependent on individual behaviours, life choices and factors of the built environment (Rendall et al., 2011). It is argued that the most influential factors relating to transportation energy use are destination, proximity, availability and practicality of alternative modes, all of which are associated with population density, network connectivity and land use mix.

A GIS-based system for urban transportation policies incorporating energy use was introduced by Arampatzis et al. (2004). In this literature, an energy consumption model was used, which takes into account different variables, such as traffic volumes, and travel speed levels under different scenarios; these are stored in the GIS database. The comparison between four scenarios in a study area indicated that the increase in public transportation mode share would result in higher traffic efficiency.

2.5.1 Urban form impact

2.5.1.1 Urban design and place-making

According to Buchanan (1988), urban design is mainly about place-making where places are not just a specific space, but all the activities and events which made it possible. It has been widely acknowledged that the combination of a variety of activities including house, work, shop, and education in one place is the key to sustainable urban development (Montgomery, 1998; Banister et al.,1997). It is widely acknowledged that the locations of human activities determine the spatial interactions or trips in the transport system, which are also the basic rationale of traffic models (Michael, 2014).

According to Marshall (2008), there is an inverse relationship between urban population density and vehicle-kilometers travelled (VKT), hence the confinement of urban sprawl could contribute to the climate stabilisation reducing VKT per capita and CO_2 emissions. In this paper, it was found that:

- Reduced sprawl, without technology innovation, decreases emissions by 10 GtC during 2005–2054 (by 0.5 GtC/yr in 2055) compared with BAU.
- The no-sprawl and infill scenarios offer 53% and 60% of a wedge, respectively, compared with BAU, with no technology innovation.

A comparative analysis between five cities in the UK was investigated by Banister, Watson and Wood (1997) to find the links between urban form and transport energy consumption. In this paper, the relationship between energy use and the physical characteristics of the city was measured. It was claimed that :

- The population density is still an important key variable but the measurement of density is not unified among different case studies.
- The amount of open space, defined as the percentage of the urban area not built up, is also a significant variable to be analysed.
- The size of the urban area has also proved important in some case studies.
- Employment, car ownership, and socioeconomic group are the most important socioeconomic variables.
- Mixed land uses and concepts of self-containment are important in reducing energy consumption in transport, but local jobs and local facilities must be suitable for local residents.

Lin and Yang (2009) studied how urban form impacts travel demand from structural analysis. By using the structural equation model with inputs of 9 latent variables and 26 observed variables, empirical research based on traffic zone data in Taipei, Taiwan, suggests that there are some direct and indirect relationships between the built environment and travel demand, as follows:

- Density is positively related to trip generation and negatively associated with private mode split.
- Mixed land use could reduce trip generation and indirectly increase private mode split.
- A pedestrian-friendly built environment could reduce private mode split.

Li et al. (2010) investigated the urban form impact on car ownership across Chinese megacities using ordinary least squares regression and discrete choice models with aggregate and disaggregate analysis. The aggregate study found that urban affluence, urban scale, and road infrastructure supply factors have significant positive effects on the city level of private car ownership across cities. A discrete choice model was employed to develop a disaggregated choice model to examine the responses to various factors (see Table 2-3) on household car ownership. The binary logit model equation captured the household trade off between the choice of owning a private car or not owning a private car. The form of the binary logit choice model was described as follows:

$$P_i = 1/(1+e^{-u_i}) \quad i=1,2 \qquad (2\text{-}3)$$

Where P_1 = probability that a household owns one or more cars,

P_2 = probability that a household does not own any car, and

u_i= utility of travel mode *i*.

Through urban form measurements, either in Beijing or Chengdu, it was claimed that the population density had a significant negative effect on private car ownership across cities. Households with private cars were found to prefer to live close to urban centres where amenities were readily available.

Table 2-3 Disaggregate data and variable description

Factor	**Parameter**
Urban form	Population density
	Distance to CBD
	Live with R4
Household characteristics	Income (high, medium, low)
	Household size
	Own house
	Own Bike
	Own Car
	Child
	Close work unit
Household head Characteristics	Age
	Marriage
	Education
	Trans convenience
	State-owned job

A comparison between Melbourne, Australia, and Riyadh, Saudi Arabia, in the aspect of urban form impact on travel demand was argued by Alqhatani, Bajwaa and Setunge (2012). In this literature analysis, modal split and commuting distance were used as transport performance indicators to investigate the interaction between travel behaviour and land use for Journey to Work (JTW). Although the two cities have similar urban form, they have significantly different urban transport systems. Melbourne has a good public transport system consisting of train, tram and bus networks, while Riyadh is heavily car-dependent with very limited public transport services. It was found that low density entailed the highest proportion of car trips in Melbourne, and the largest proportion of car travel to work were observed in low-socioeconomic areas in both cities. The population density in one area has more impact on mode choices for commuters than socioeconomic characteristics, and the usage of the car and public transport were influenced by urban form rather than by socioeconomic variables.

A literature review on the effects of the built environment on bicycle commuting was proposed by Zhao (2014) using regression analysis through the multinomial logit (MNL) model. Based on the travel data from some interview surveys and official census, some results were found as follows:

Urban form indicators*:*

- A one-unit increase in the jobs-housing balance would result in an increase of 1.5 times the odds of choosing to commute by bicycle.
- Destination accessibility has critical effects on the use of bicycle transportation. A longer travel time is related to less of a possibility of cycling.

- A higher employment density within a sub-district might encourage more likelihood of choosing to commute by bicycle instead of motorised mode.

Urban design indicators:

- Increasing the number of local street crossings could lead to more odds of travel by bicycle; in contrast, the larger number of main-road crossings around a community might decrease the likelihood of bicycle travel owing to the worries of higher risks of traffic accidents and traffic pollution.
- The level of exclusive bicycle lanes has significant relevance to the use of the bicycle but with less elasticity compared to the variable of mixed environment.
- A closer proximity to public transport facilities tends to decrease the odds of bicycle travel because public transportation could in some measure substitute for the bicycle.

However, sometimes the relationship between the urban form indicators and travel patterns is not statistically significant in some cities. According to Ewing and Cervero (2010), the 6D variables (Density, Diversity, Design, Destination accessibility, Distance to transit and Demand Management) could be used as measures for evaluating the relationship between the built environment and the transport energy used. The literature inspected more than 200 studies of cities in North America that quantitatively relate characteristics of the built environment to measures of travel. Many studies were excluded owing to their limitation in population and trip purposes or subjective characteristics. The concept of elasticity was proposed to form a common measure of different effect size. It was concluded that for all of the variable pairs, the relationships between travel variables and built environmental variables are inelastic. The weighted average elasticity with the greatest absolute magnitude is 0.39, and most elasticities are much smaller.

2.5.1.2 New urbanism

After World War Ⅱ, the development from city to suburb has been prevalent in western countries. Although to some extent the urban sprawl pattern improves people's quality life, it is argued that the urban sprawl could lead to leapfrog development, land use extension, segregated land use and automobile dependence (Bruegmann, 2005; Hayden, 2003). In response to the issues resulting from suburbanisation and urban sprawl, the new urbanism has arisen since 1980s to re-examine the conventional conceptions, such as single-use housing projects, highly car-dependent developments, and segregated commercial centres that had become the "norm" (Jacobs, 2016).

In general, the new urbanism includes two types of development patterns:

TND (Traditional Neighbourhood Development): based on a land parcel with a 400-meter radius, it is recommended that all the houses are located within a 3-minute walk to the neighbourhood park, considering the diversity and balance of living, work, shopping and recreation. All the destinations are connected with street networks that are designed to encourage walking and cycling, and restrain car driving and parking.

TOD (Transit-Oriented Development): it is suggested that the community is developed along light rail networks and bus lines with all the origins and destinations placed within walking distance of stops. Each TOD is a concentrated community with multiple functions so that residents can readily access work, shops and all kinds of facilities by walking.

With the emergence of the new urbanism, some significant elements pertaining to sustainable cities have been highlighted: that car driving mobility may be replaced by active modes like walking and cycling if essential activities, including housing, working and shopping, are accessible within walking distance and an interconnected network, including streets, sidewalks, and cycle ways, is available (Handy, Boarnet, Ewing, & Killingsworth, 2002; Duany, Plater-Zyberk, Krieger, & Lennertz, 1991; Katz, Scully, & Bressi, 1994).

A basic consensus has been claimed that the compact city with mixed land uses would reduce travel demand by petrol cars if, for example, people can live in the vicinity of their workplaces (Marshall, 2008). Also, the new urbanism can encourage more physical activities compared to conventional suburbs due to their walking more for utilitarian purposes other than for leisure (Rodriguez, Khattak, & Evenson, 2006).

2.5.2 Sustainable transportation

A great deal of research on the definition of sustainability has been proposed during recent years. The Brundtland Report (1987) defined sustainability as ensuring that development meets the need of the present without compromising the ability of future generations to meet their own needs. Diamond (2005) claimed that societies either choose to collapse or they manage their resources and relationship situations through adopting shared cultural values in order to find a sustainable way of life. Dincer (2000) regarded renewable energy resources as the most efficient solutions to alleviate the rapid consumption of finite resources; however, there are several barriers that prevent the penetration of renewable energy resources, such as cost-effectiveness, lack of infrastructure and consumer acceptance, technical bottlenecks and new environmental pollutions (Painuly, 2001).

A literature view of the challenges and implications of energy use for sustainable road transportation in China was carried out by Hu et al. (2010). The review looked at sustainable road transportation development in terms of energy consumption and environmental management in the context of China, with an emphasis on research about major challenges and constructive policies to cope with these problems. Several challenges concerning road transportation development during Chinese modernisation, such as energy security, low efficiency and environmental challenges were analysed and a number of solutions were proposed, as follows:

- developing clean vehicles and alternative fuels;
- emphasising vehicle fuel economy and control of emissions;
- improving traffic management and facilitating urban public transport; and
- enhancing management of private vehicles.

When it comes to 'sustainable transport', the dominant transport engineering method is mainly focused on vehicle-based mobility with the assumption that car ownership would increase and fossil fuel consumption is not constrained. In response to climate change and environmental pollution, the planning for sustainable transport with more consideration for renewable energy and public transport has been promoted in recent years. However, the transition to large-scale use of this energy also presents some difficulties (Pimentel et al., 2002). Fundamental problems with biofuels include very low EROI (Pimentel & Patzek, 2005), water and land use and competition with food resources (Babcock, 2012). The lifecycle cost for electric vehicles, even with scenarios of mass production, may be too high (Cuenca, Gaines & Vyas, 1999). Biofuels are currently a mandated proportion of consumer fuel supply in the USA and Europe, but it is not clear that this policy has resulted in reduced GHG emissions from transport (OECD, 2010).

Hybrid vehicles reduce rush-hour pollution and have marginally better fuel efficiency, but they have not achieved more than 5% of market share in any country where they are available and even subsidised, such as California (Peter, 2015). Hydrogen fuel cell cars have had a lot of media attention and government research investment, but there are serious doubts about the feasibility of hydrogen, or in fact their sustainability (Romm, 2014). Some countries like Taiwan have seen a massive shift to scooters and motorcycles, which use much less fuel per passenger km than cars (Pei-Chang et al., 2013).However, the noise and pollution from two-stroke engines have become a major issue and the government of Taiwan and China have set a policy to switch to electric scooters (Alan, 2010). All of the alternative vehicle platforms and fuels still would require a massive network of roads and all of the attendant costs associated with private vehicle mobility (European Expert Group on Future Transport Fuels, 2011).

It is believed that public transportation is the sustainable alternative to personal vehicles (Nikki, 2006). Electric trams and trains can carry many more passengers per unit of fuel consumed than passenger cars (Kenworthy, 2003). Diesel buses and trains are also more fuel efficient, but only if rider utilisation is near capacity (John, 2012). Many cities struggle with the cost and construction of fixed rail infrastructure and have taken over parts of the existing roadway system for Bus Rapid Transport (BRT) systems.

Gan (2003) pointed out that the externality costs, such as health care, environmental damage and land use should be considered in response to the reduction of air pollution and energy efficiency. In this literature review, the current government policy of encouraging private car ownership was challenged and some suggestions relevant to the greening of road transportation were proposed as well. Efforts need to be made to use more economic incentives for emission reduction, improve public transportation and promote technical innovation. However, the transition process is not always successfully implemented as expected.

2.5.3 Mode shift to walking and cycling

Walking and cycling are virtually free, they do not pollute and can be used by most people. However, the main constraints to walking and cycling are accessibility: distance, good quality surfaces, safe conditions and traffic controls, and environment (e.g. shade, pollution, and wind exposure) (Sony & Piotr, 2005; Pooley & Ebooks, 2013; Saelens & Handy, 2008). Many of these accessibility factors can be improved by engineering and urban design. However, distance is the spatial relationship between origins and destinations, and will be affected by obstacles that must be negotiated. The geographical distances between homes and work locations or homes and other destinations like shopping and schools are entirely determined by the urban form.

Martens (2013) argued that the bicycle indeed relieves transport poverty and transport-related social exclusion but was of limited importance as a means of access to employment opportunities. Through the two surveys in a medium-sized city in Netherlands, it was claimed that for low-income households, the bicycle could offer a feasible alternative because of its low costs, but the lack of a car also poses a risk in job seeking. In the aspect of social networks, walking and cycling play a primary role to maintain social contacts at the neighbourhood level but fail to satisfy the need to meet family and friends outside the city.

A comparative analysis of the costs of travel modes including automobiles, transit and bicycles in Chinese cities was introduced by Wang (2011). In this literature review, seven travel modes are calculated by comparing the sum of land, capital, operating, travel time, safety and environmental costs at different traffic volumes in hypothetical radial and circumferential commuting corridors. Using detailed estimates of private and social costs, the full cost of each mode is minimised by optimising infrastructure investment and operation plans (see Table 2-4).

Table 2-4 Estimated urban modal environmental and safety costs in Chinese cities (in 2005 RMB cents per VKT).

Mode	**Environmental costs**	**Noise**	**Climate change**	**Total**	**Safety costs**
	Air pollution				
Auto (average)	2.50	0.65	2.00	5.15	14.00
Auto (expressway)	1.43	1.03	1.33	3.79	7.00
Auto (arterial/local)	3.57	0.28	2.67	6.51	21.00
Bus (expressway)	3.57	2.38	6.33	12.28	21.00
Bus (arterial street)	8.93	1.75	12.67	23.35	63.00
BRT	3.57	2.38	6.33	12.28	31.50
LRT	0.00	4.75	26.00	30.75	31.50
Metro (underground)	0.00	0.00	26.00	26.00	15.80
Metro (elevated)	0.00	4.75	26.00	30.75	15.80
Bicycle	0.00	0.00	0.00	0.00	63.00
Walking	0.00	0.00	0.00	0.00	75.60

Through comparing the full costs of different passenger modes, some conclusions are drawn as follows:

- The bicycle is the most cost-effective mode for short trips but not as competitive as the bus on ring corridors in the city center due to higher safety and parking costs.
- The three bus modes provide more desirable choices than rail in Chinese big cities.
- The use of automobile as the primary commuting mode in Chinese cities even at low level travel volumes is not as efficient as expected.

3. Methodological review

Understanding the characteristics of human travel behaviour is the critical issue for transport modelling, policy making and urban infrastructure development. Trip distance plays a vital role in determining human travel patterns, so it is necessary to learn about the distance distribution of human travel activities, thereby formulating a mathematical tool for the following model development and associated adaptation analysis. In addition, a wealth of models regarding shopping activities and commuter trips have been proposed to characterise the spatial interaction between destinations and origins. This chapter describes cutting edge approaches to simulating human travel distance distribution, reviews the methods for shopping activity and commuter activity modelling respectively. Finally, some analysis tools for adaptation developed by AEMS Lab are introduced and reviewed.

3.1 Quantifying human travel behaviour

Human travel behaviour is a pre-requisite for transport research. How to precisely describe and predict the distribution of travel distances, which are a human-related performance, is a critical step for developing transport models; however, it is impossible to create a universally perfect formula to characterise human behaviour. Basically, there are two ways to address these problems: one is to conduct travel surveys to obtain respondents' locations and trip destinations; and the other one is to use rules of thumb to estimate trip distributions. A travel survey is a pragmatic method that can reveal subjective factors about location and mobility decisions (Michael, 2004) but it requires great effort and much time. Mathematical models are also based on empirical data or observations but can be applied in unknown situations although sometimes the validity of the conjectures have to be calibrated.

State of the art modelling for human travel behaviours is the estimation and simulation of trip distance distributions. Predicting human mobility has been an essential subject in various research fields, including transportation, geography, business and epidemiology (Barthélemy, 2011; Batty, 2008). A body of research has been carried out to unravel the nature of human trajectories and locations thanks to the emergence of big data and improvement in technology. A study by Gonzalez, Hidalgo, and Barabasi (2008) establishes that the distribution of human displacements is well approximated by a power law, as follows:

$$P(\Delta r) = (\Delta r + \Delta r_0)^{-\beta} \exp(-\Delta r/\kappa) \qquad (3\text{-}1)$$

with exponent β=1.75$\pm$0.15 and $\Delta r_0 = 1.5$ km. The research findings indicate that the travel patterns of human beings could be quantified as a spatial decay distribution, the highest probability occurring in a few frequently visited locations. According to Wang et al. (2007), the distribution of human travel distance is similar to electron cloud phenomenon (see Figure 3-1), namely the probability of trips (assuming these are mostly trips by car only) appearing near to origin is relatively low, then it gradually goes up as the travel distance increases; after peaking at a certain point, it begins to decrease with the increment of distance. By using the electron cloud model from quantum mechanics, a residential trip distribution model was formulated using the following equation:

$$f(r) = \frac{4r^2}{{a_0}^3} e^{-\frac{2r}{a_0}} \qquad (3\text{-}2)$$

where r is the travel distance, and a_0 is the coefficient to be calibrated.

The model was validated by authors with the sample of survey data in Changchun, China, and San Francisco, U.S.A. with good fitting results. Shi et al. (2008) employed probability theory and statistics under some hypothesis conditions to simulate residential trip distribution; it was found that the Rayleigh distribution function has a similar pattern to the trip distance distribution (see Figure 3-2). Moreover, there is only one coefficient λ in Rayleigh function, which to some extent facilitates the fitting process. Based on the sample data in 10 cities, the calculation indicates that the function of trip distance distribution can be expressed through quantitative analysis and nonlinear regression. The coefficient λ is sensitive to the urban boundary, travel modal split and urban form.

Form of Rayleigh distribution Function:

$$F(r) = 1 - \exp(-0.5\lambda r^2) \qquad (3\text{-}3)$$

Form of Rayleigh density function:

$$f(r) = \lambda r \exp(-0.5\lambda r^2) \qquad (3\text{-}4)$$

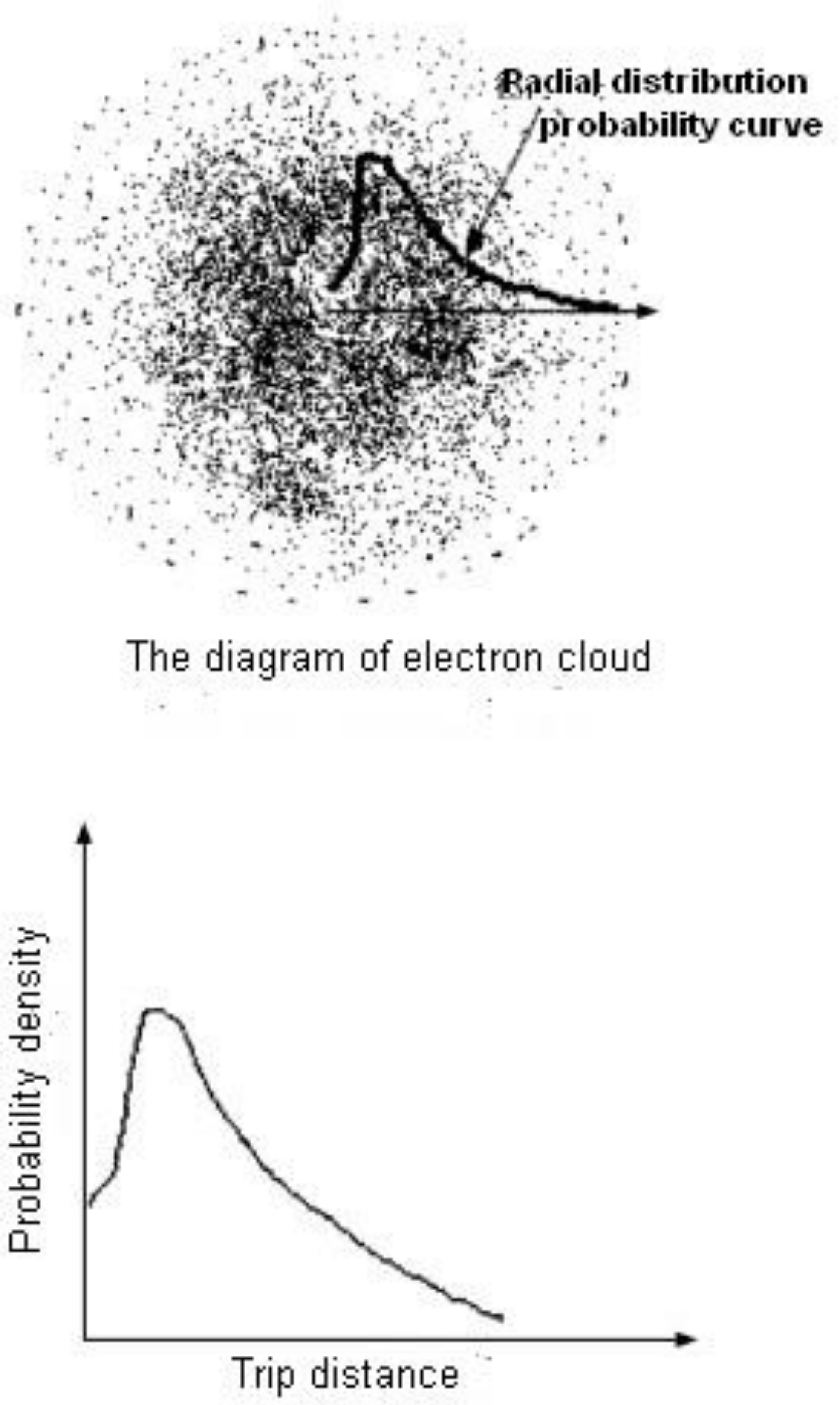
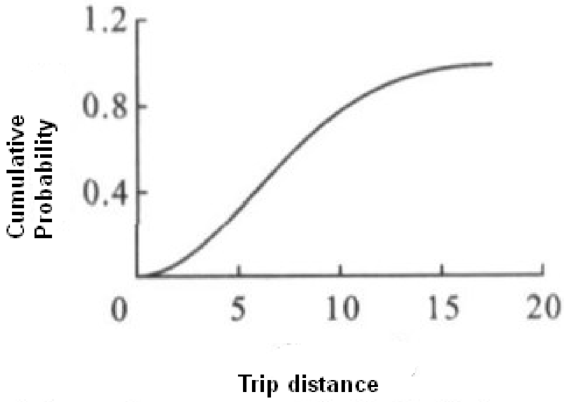
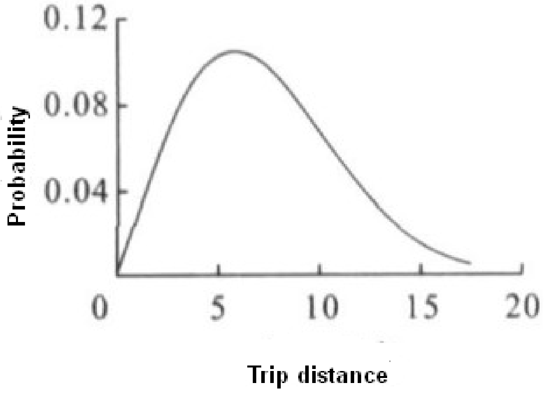


Figure 3-1 Similarity between electron cloud and human trip distance distribution



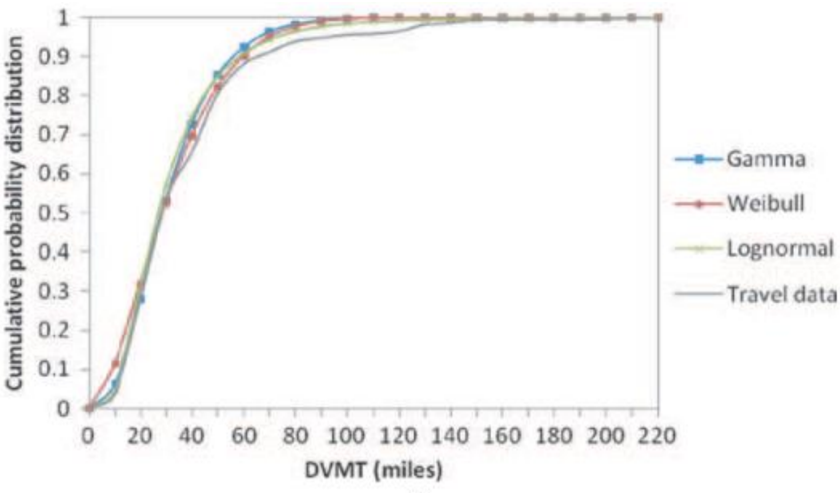
a.Basic form of Rayleigh distribution function



b.Basic form of Rayleigh density function

Figure 3-2 Forms of Rayleigh distribution

Based on the daily vehicle mile travelled (DVMT), Lin et al. (2012) made a validation of Gamma distribution in the context of plug-in hybrid electric vehicles (PHEVs). In this study, three plausible distribution function forms were considered, including Gamma, Weibull and lognormal. One example dataset (containing 459 DVMT observations for a particular vehicle) is shown in Fig 3-3. From the statistics point of view, there is no significant difference between the three distribution functions in fitting the real travel data. However, the Gamma distribution function was used in this paper to approximate the variation of DVMT owing to its advantage of easier mathematical manipulation and fewer prediction errors. The results showed that the gamma distribution is a reliable assumption for the random DVMT, facilitating the development of mode choice models, and the quantification of adaptive capacity range.



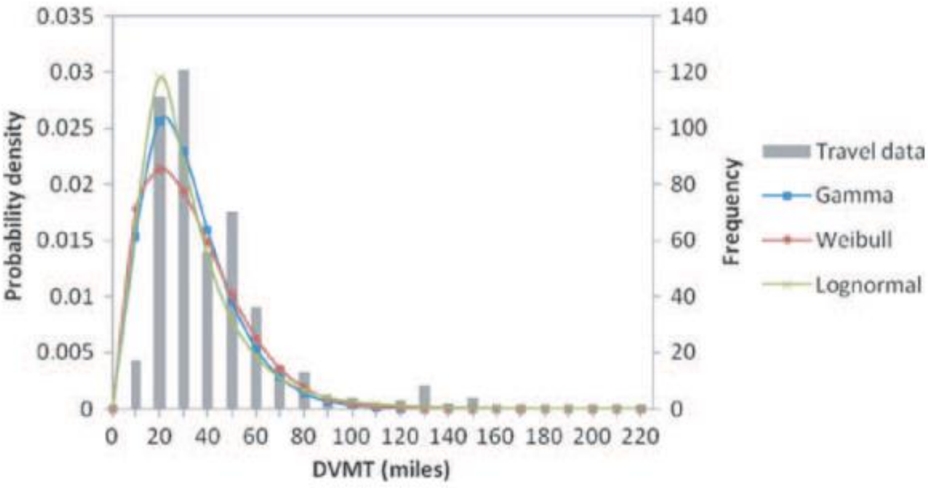


Figure 3-3. Comparison of fitted distributions and travel data (one driver example)

((a) cumulative probability distributions and (b) probability density distributions.)

John (2012) analysed the car driving patterns in the U.S.A. from the 2009 National Household Travel Survey; these research findings also support the above hypothesis. Figure 3-4 is the overall trip distance distribution histograms in the U.S.A.; Figure 3-5 shows the daily trip durations and distances distribution. It can be seen that: 1) On the basis of travel distance, the distribution curve is more like the electron cloud model; 2) On the basis of travel time, the distribution curve is similar to the Rayleigh distribution model. In addition, the driving distance and times vary with trip purposes. Figure 3-6 shows the average trip distances and times to 35 different destination types. Typically, the intercity trips are the longest, with the first three being ‘Rest or relaxation’, ‘Funeral’ and ‘business errands’. The majority of daily activities can be accomplished within 15 miles, and the mean trip length over all the reported vehicles is 18.1 minutes and 9.3 miles.

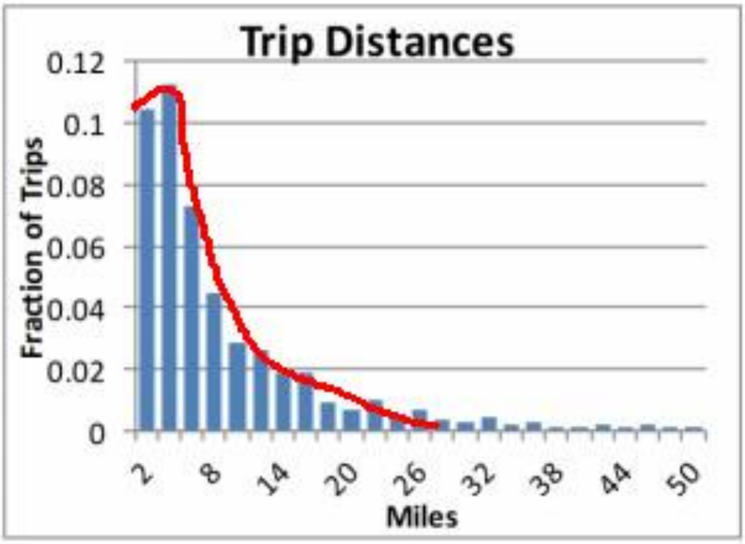
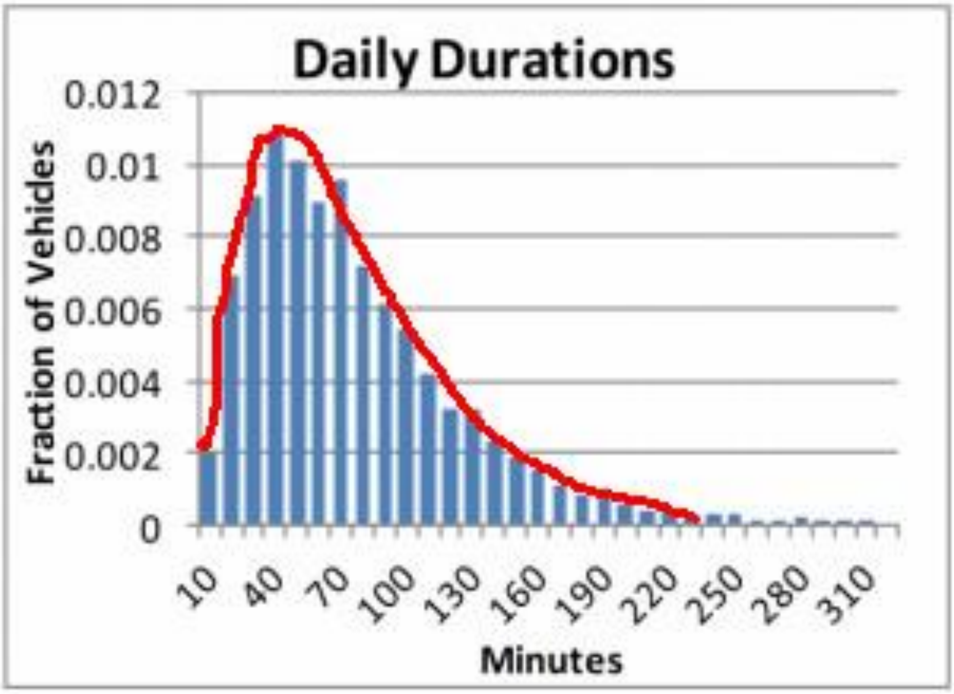


Figure.3-4 Histograms of average trip distance



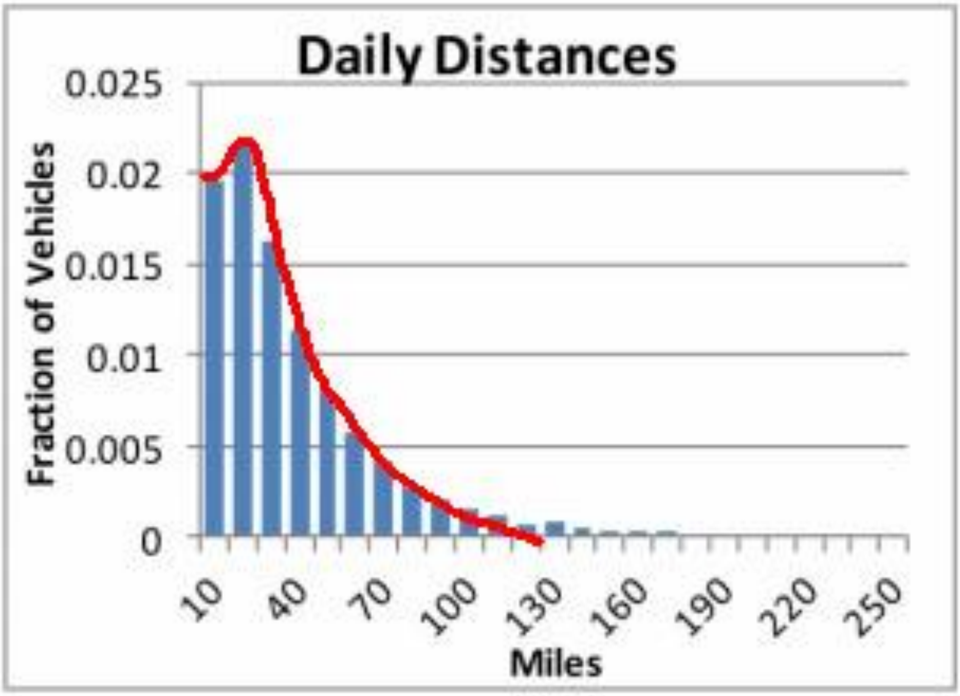


Figure 3-5 Daily car trip patterns based on distance and time

Destination	Average Minutes	Average Miles
Rest or relaxation/vacation	44.7	34.8
Attend funeral/wedding	36.5	24.4
Attend business meeting/trip	34.9	24.8
Visit friends/relatives	25.4	16.4
Other work related	24.4	13.3
Go to work	22.7	12.4
Go out/hang out: entertainment/theater/sports event/go to bar	22.3	11.9
Medical/dental services	21.7	10.0
Family personal business/obligations	21.7	11.5
Go to school as student	21.6	10.9
Social event	21.0	11.3
Social/recreational	21.0	11.1
Take and wait	20.3	10.2
Visit public place: historical site/museum/park/library	19.2	8.7
Home	18.7	9.1
Attend meeting: PTA/home owners association/local government	18.2	8.2
Use personal services: grooming/haircut/nails	17.0	7.5
Buy gas	16.2	9.5
Transport someone	16.1	7.8
Use professional services: attorney/accountant	16.1	7.6
Pet care: walk the dog/vet visits	15.7	6.7
School/religious activity	15.3	6.5
OS - Day care	15.2	7.0
Go to gym/exercise/play sports	15.2	8.7
Pick up someone	14.9	6.9
Shopping/errands	14.8	6.7
Drop someone off	14.3	6.4
Go to religious activity	14.2	6.3
Get/eat meal	14.1	6.3
Meals	13.6	6.1
Go to library: school related	13.5	4.7
Buy goods: groceries/clothing/hardware store	13.4	5.4
Buy services: video rentals/dry cleaner/post office/car service/bank	12.1	4.8
Return to work	11.4	4.6
Coffee/ice cream/snacks	10.4	4.5

Figure 3-6 Average driving times and distances to different destination types

Liu et al. (2009) made a comparative analysis of car driving patterns between Beijing and New York. With respect to the car trip distance distribution, the two cities have similar varying curves as the distance increases (see Figure 3-7). It can be seen that a phenomenon of bimodal distribution exists in both cities, at 1-3 miles and 5-10 miles respectively. Also, the short distance (between 1-3 miles) trips in both cities outnumber the medium distance trips, indicating high dependency on the private car. The distribution curve of New York is more similar to the Rayleigh distribution except for a short hump between 5-10 miles.

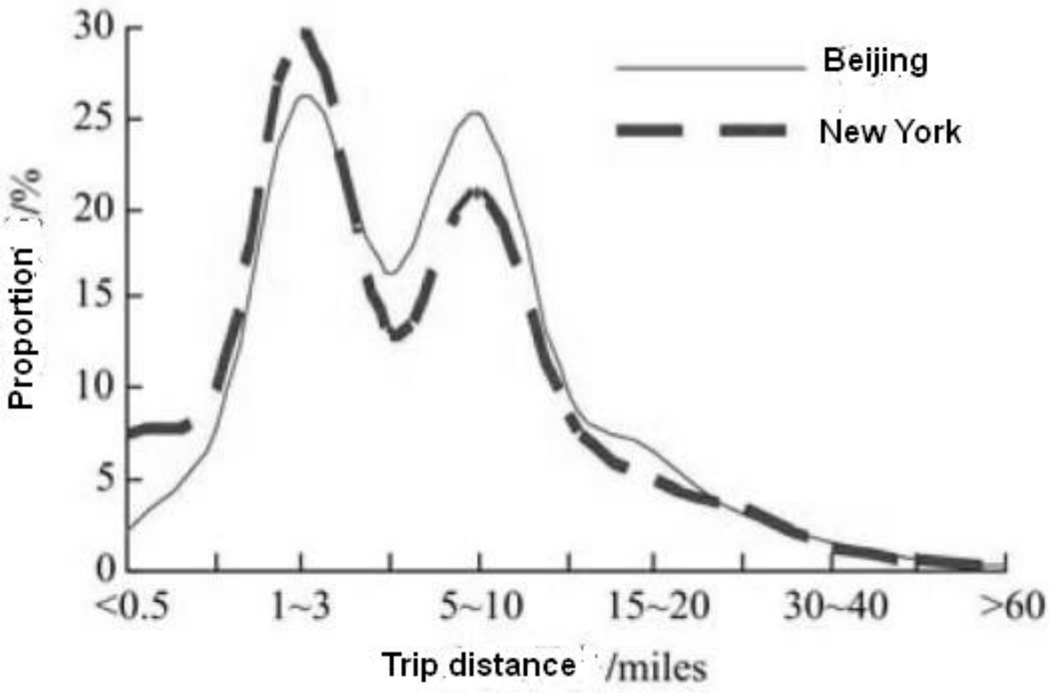


Figure 3-7 The bimodal Car trips distribution in Beijing and New York

3.2 Travel activity modelling

3.2.1 Shopping model

3.2.1.1 Huff model

A commonly accepted model to characterise the spatial interaction between consumers and shopping facilities is the Huff model. It is analogous to the Law of Gravity in physics. Huff (1963) formulated a probabilistic shopping model stating that the attractiveness of a shopping store, i.e. the probability of shopping demand at location *j*, is a function of the size of the store and the distance between an origin *i* and the store *j*. A prototype version of the Huff model can be mathematically expressed as follows:

$$P_j = \frac{A_j}{d_{ij}^{\lambda}} \qquad (3\text{-}5)$$

where λ is the distance decay parameter to be calibrated. This model is a simplified method to quantify human shopping activities, in which a number of factors that might affect consumer choices are neglected. In fact, personal attributes such as income, individual preference, age, gender, and types of stores as well as price advantages also play vital roles in shopping activities .

3.2.1.2 Retail hierarchy

The retail sector is a major driver for urban development and accounts for nearly 20% of driver travels in New Zealand (MOT, 2015). The travel demand derived from retail activities also has significant implications for the operation of the regional transport network (Susan et al., 2013). There is no unified definition of the retail hierarchy; basically, it is a concept that classifies and ranks the level of retail services. There are a number of factors contributing to the ranking of retail sectors in a region, such as the order of goods, population flow, accessibility level, travel cost, and floor space. Frequently purchased ‘convenience’ goods, such as food, drink and paper are low-ordered goods without the need to occupy a large space because they are not expensive and do not require shoppers to travel long distances (Jill,2011). For example, a grocery store can thrive on a population of less than 10,000 (Handy, 1993). However, frequently purchased ‘comparison’ goods like furniture, household appliances, and jewellery are high-ordered goods with a large market area because they are expensive, bulky and require shoppers to travel longer distances. They are usually sold in supermarkets, department stores or regional centres but sometimes they are found at neighbourhood stores owing to the need for businesses to capture a greater market share (Jill,2011).

According to the classification of the U.K. (Internetgeography, 2009), the shopping hierarchy is depicted as a pyramid structure (Figure 3-8). At the bottom are corner shops, which mainly sell low-order goods; they are greater in number than other shopping facilities. At the top are regional shopping centres and the CBD where the high-order goods can be bought and compared. Especially with the increase of human mobility (i.e. the increased car use), people can travel further for shopping and buy in bulk.

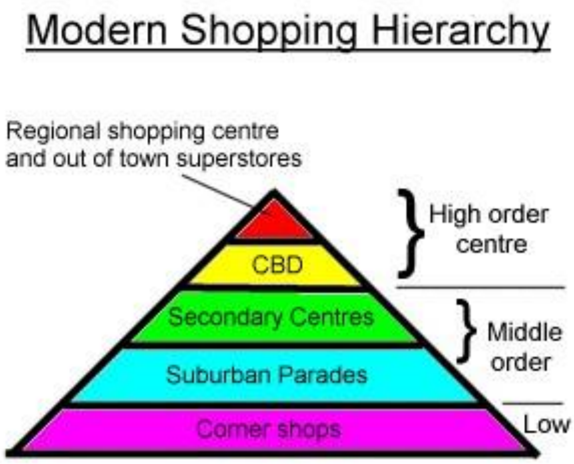


Figure 3-8 Modern shopping hierarchy

The hierarchy of retail trade was first defined by Berry (1967) as centres offering distinct goods and services to distinct market areas. The Urban Land Institute's (1985) definition of the hierarchy of shopping centres is shown in Table 3-1.This hierarchy is based on the assumption that customers would be arriving by automobile instead of by foot or bike.

Table 3-1 The hierarchy of shopping centres

Type of Centre	Minimum Population Needed	Radius(miles)	Driving time(minutes)
Super-Regional	300,000 or more	12	30
Regional	150,000 or more	8	20
Community	40,000 to 150,000	3 to 5	10 to 20
Neighbourhood	2,500 to 40,000	1.5	5 to 10

Source: Urban Land Institute, Shopping Center Development Handbook, Second Edition (Washington, D.C.: Urban Land Institute,1985)

According to Susan et al. (2013), retailing was grouped into four categories as follows:

- Core retail – durable and comparison goods, such as household appliances, clothing, footwear, and stationery.
- Trade retail – garden centres, DIY materials and hardware, and landscaping.
- Food and liquor retail – supermarkets, specialised food, other food and liquor purchased for consumption, not on the retail premises (excluding prepared meals).
- Food hospitality and household services – restaurants, takeaway food, bars, clubs taverns, and household services that occupy storefront locations such as drycleaners, travel agents, and hair dressers.

Based on the electronic transactions data in New Zealand (MarketView Ltd, 2011), food and beverage is found to be the largest category of expenditure (32%), followed by the core retail (21%). Moreover, the Fairgray (2012) study shows that two-thirds of expenditure occurred in the 96 shopping centres in Auckland (see Figure 3-9). In the aspect of geographical area and travel distance, the study observed a positive correlation between centre size and catchment extent, where larger centres have a larger radiant area. Table 3-2 (adapted from Fairgray (2012)) shows the cumulative road network distance from within, which different shares of the centres/areas' sales originate from, decomposed by retail category. It can been seen that, on average, almost half of the sales originated from households located within 5 km, and nearly 80% of sales from within 13 km. Convenience goods, such as food and liquor, have outstanding features of shorter travel distance.

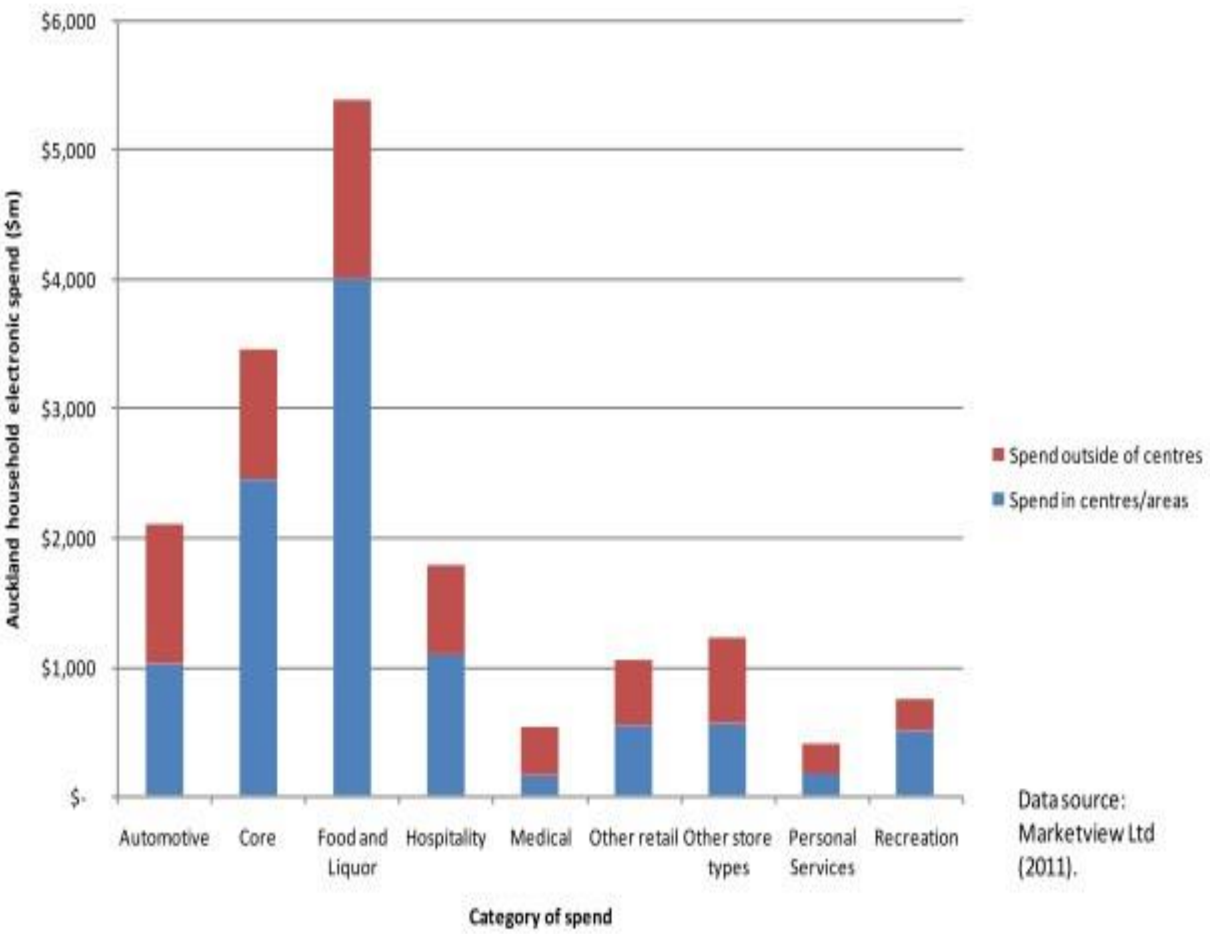


Figure 3-9 Auckland household electronics spend in Auckland centres and elsewhere, 2011

Table 3-2 Road network distance (kilometres) containing cumulative shares of Auckland households

Spend Category	Cumulative shares of Auckland household spend			
	50%	60%	80%	90%
Automotive	5	7	14	23
Core retail	7	9	16	23
Food and liquor	4	5	9	15
Hospitality	6	9	15	22
Medical services	16	19	27	36
Other retail	7	9	17	24
Other store types	7	10	18	26
Personal services	7	10	19	27
Recreation	8	10	16	23
Total	5	7	13	22

Jian et al. (2007) investigated the evolution features and mechanism of shoppers' behaviour in Beijing with respect to spatial structure and travel distance. It was found that the average shopping distance in Beijing tended to decrease over 10 years (see Figure 3-10) and the shopping distance for basic needs, including food and daily necessities are within 2km regardless of the location of residence. The low-order shopping travels around residential place have gradually increased, the regional shopping centres and shopping malls have great attractiveness to local inhabitants thanks to the decentralized pattern and multi-polarized development of shopping facilities.

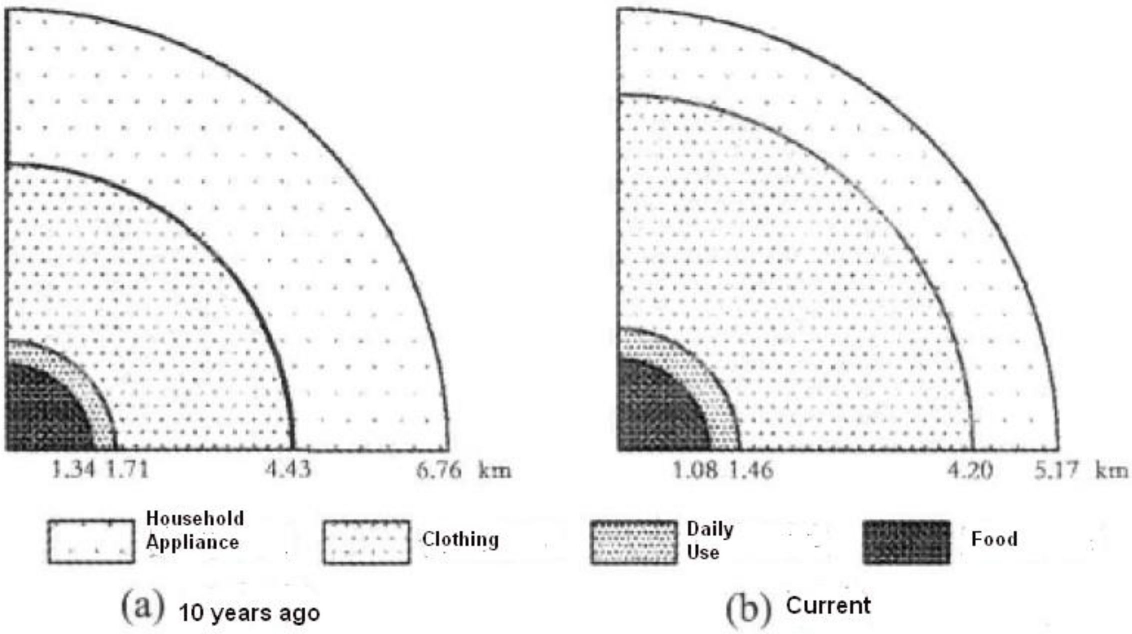


Figure 3-10 The evolution of the spatial structure of shopping behaviour of Beijing residents

3.2.1.3 Attractiveness

The measure of attractiveness has been reported by Dennis et al. (1999a) based on a questionnaire survey at six UK shopping centres of different sizes from small downtown sub-regional to large regional suburban centres. A regional centre has a gross retail floor space of greater than 50,000m^2 and a sub-regional one from 20,000-50,000m^2. Respondents rated the importance of each of 38 attributes between two shopping centres, such as ‘quality of stores’, ’cleanliness’ and ‘availability of toilets’. The perceived travel distance and time as well as respondents’ personal attributes (e.g. age, location of residence) were included in the questionnaire to investigate the distribution of socio-economic characteristics for shopping activities.

The selling area could be used as a proxy indicator of attractiveness to compare two competitive shopping centres (Dennis et al., 2002). A mid value of 75% has been adopted as the defining level of a substantial competitor. For example, if a smaller shopping centre has an attractiveness of less than 75% of the studied larger one, the smaller is inferior to the studied one in the hierarchy. A unified attractiveness scale was presented by Mintel (1997) based on the numbers of retail outlets, in which multiples are scored higher and certain famous brand retailers are given a higher weight in affecting consumers' images of shopping centres.

3.2.1.4 Shopping travel distribution

Research on the spatial-temporal choice of shoppers' behaviour and their differences between weekday and weekend was carried out by Ma and Chai (2011). Based on the travel survey data, it was found the shopping trip distance distributions have different patterns on weekdays and weekends (Figure 3-11). During weekdays the proportion of shopping within walking distance (0-1km) is about 60%; however, the longer shopping distances (greater than 5km) only account for 10%. In comparison, during weekends the proportion of shopping within walking distance accounts for 40%, and 20% of shopping activities occurred beyond 5km because inhabitants have more freedom to choose their travel activities at weekends.

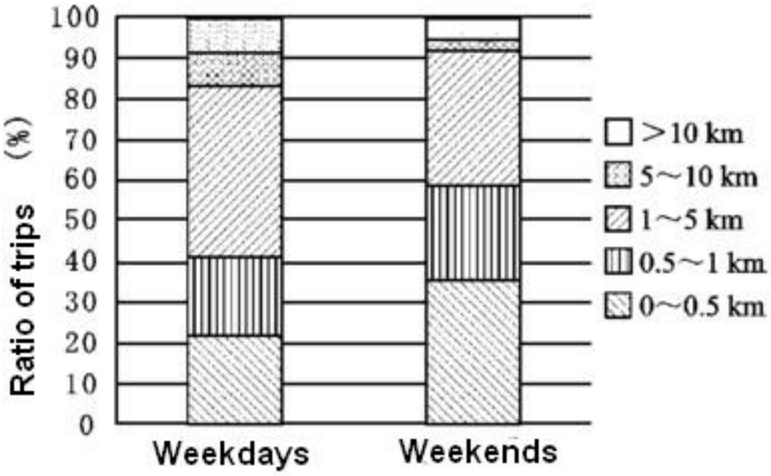


Figure 3-11 The spatial characteristics of individuals' shopping activity

Jones and Simmons (1990) studied the travel time differences between convenience and comparison goods in the U.S. based on empirical data from Young (1975) (see Fig. 3-12). It was found that the average number of trips for any particular goods are negatively related to driving time. Shoppers are prone to travel a long time to access some regional shopping centres for comparison goods. If a shopping centre is sufficiently attractive, shoppers would like to go there despite the longer travel distance (Finn & Feinbeg, 2000).

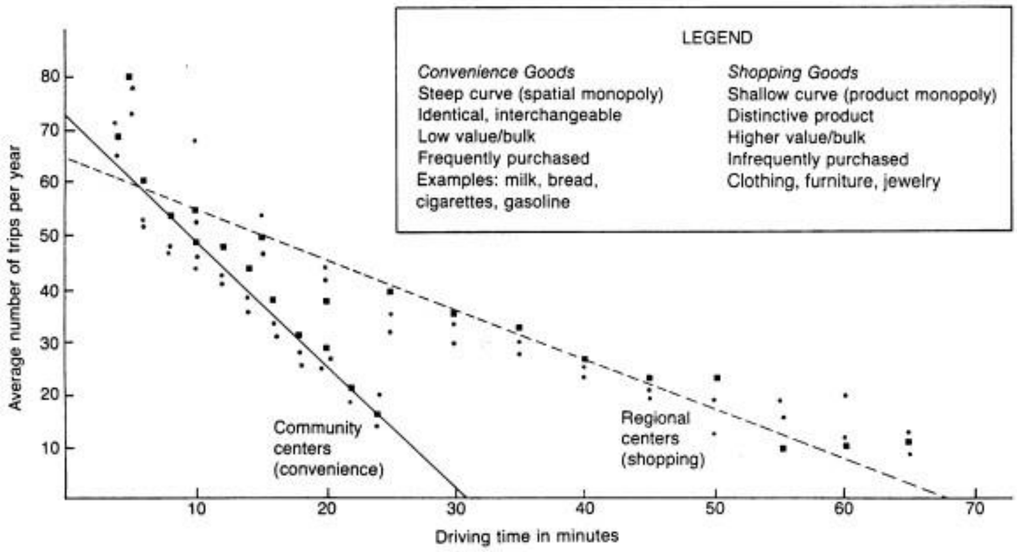


Figure 3-12 Travel time decay curves comparing convenience and comparison goods

Kelly et al. (2012) made an empirical study on the impacts of built environment on non-work trips and how consumers spend by travel mode. The research findings still provide evidence that automobile use is the dominant travel mode in the U.S. for non-work destinations and non-motorised travel are mainly situated in the concentrated urban area. However, with respect to the trip length distribution, it was found that the percentage of motorised trips shorter than 3 miles almost accounts for 50%. Figure 3-13 shows the average trip distance by mode of travel and establishment type. Transit riders travel the farthest, on average, for all destinations, followed by automobile users. Not surprisingly, walking trips tend to be shorter than bicycling, transit, and automobile trips. In fact, pedestrians travel longer distances, on average, than the ¼ mile “rule of thumb”, commonly used in planning. Bicyclists travel shorter distances, on average, to supermarkets and convenience stores than restaurants and drinking establishments. Again, this may be due to the burden of carrying purchases.

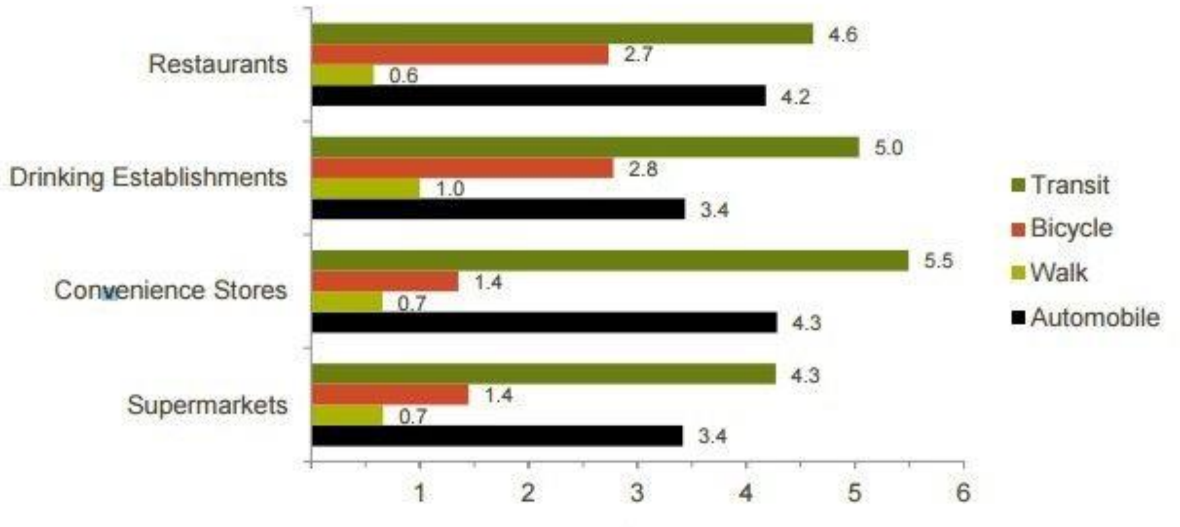


Figure 3-13 Average trip distance from origin to establishment

3.2.2 Commute model

Commuting trips play a significant role in human mobility, which are highly reliant on motorised travel mode in high-income countries (Poumanyvong, Kaneko, & Dhakal, 2012). The continuous increase in the commuting distance has been a challenging problem for urban smart growth and sustainable development. In developed countries like France, the average distance from home to work has grown by 16 percent over the last decade (Aguilera, 2005). According to the OECD (2005), commuting distance has increased in the OECD countries with 1%-16% employees commuting between regions every day. When it comes to urban transport resilience, it is argued that the built environment has a significant impact on travel behaviour, in which the density, land-use mix and distance to the destination are the most influential factors (Cervero, 2002). Accordingly in order to understand people’s travel mode choice and mode shift potentials under different built environments, the trip distance is a critical variable to be considered. However, little attention has been paid to the study of trip distance distribution.

How to model commuter activity remains an important issue for planners and policy-makers. Gargiulo, Lenormand, Huet, and Espinosa (2011) proposed a commuting network model with only one parameter based on the conventional gravity law governing commuter's choice for workplace location. The travel survey results for several regions in France show that the commuting distance distribution in each region roughly exhibits a bell-shaped curve with the increase of distance (see Figure 3-14).

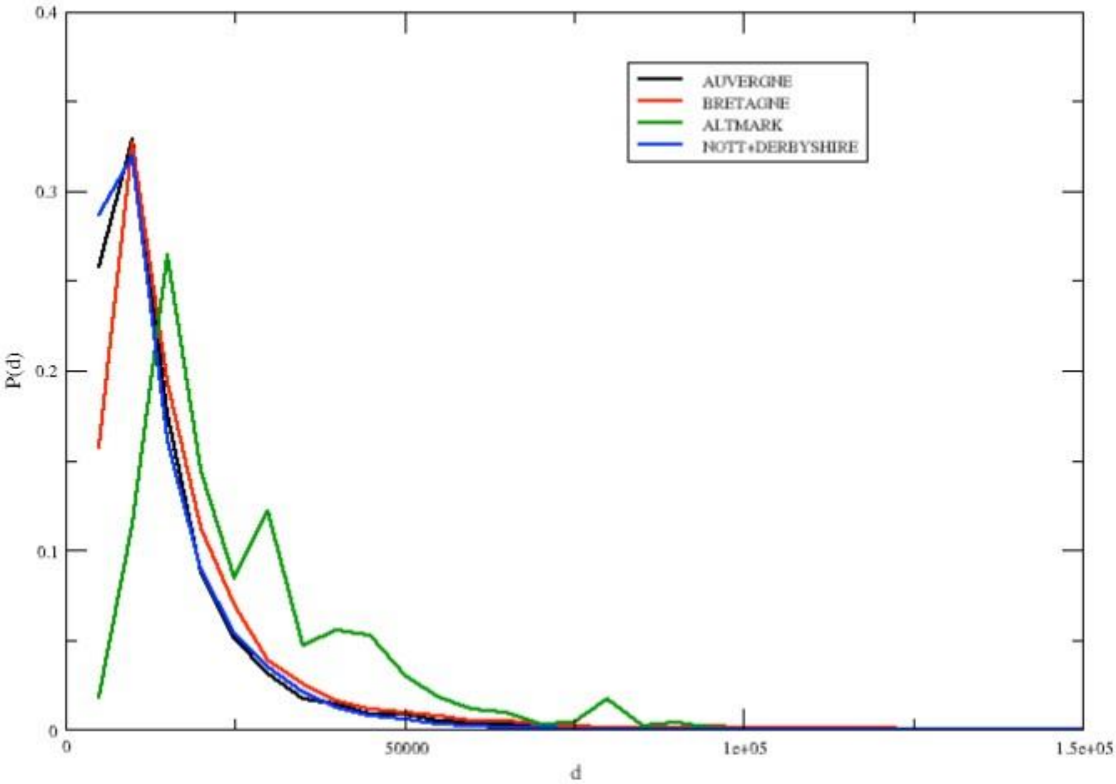


Figure 3-14 Distribution of commuting distances for the selected study regions

Using a set of data sets for a polycentric region in Germany, Ahlfeldt & Wendland (2016) developed an employment potential capitalisation model. The comparison between the estimated spatial decay from the developed model and the commuting gravity model based on actual commuting data shows that the decay in commuting probabilities can be inferred from the spatial distribution of land use prices and employment with no commuting data available. The fitted curve of commuting probability vs. travel time is plotted as shown in Figure 3-15. It can be found that the probability of a location basically decreases with the increase of travel time.

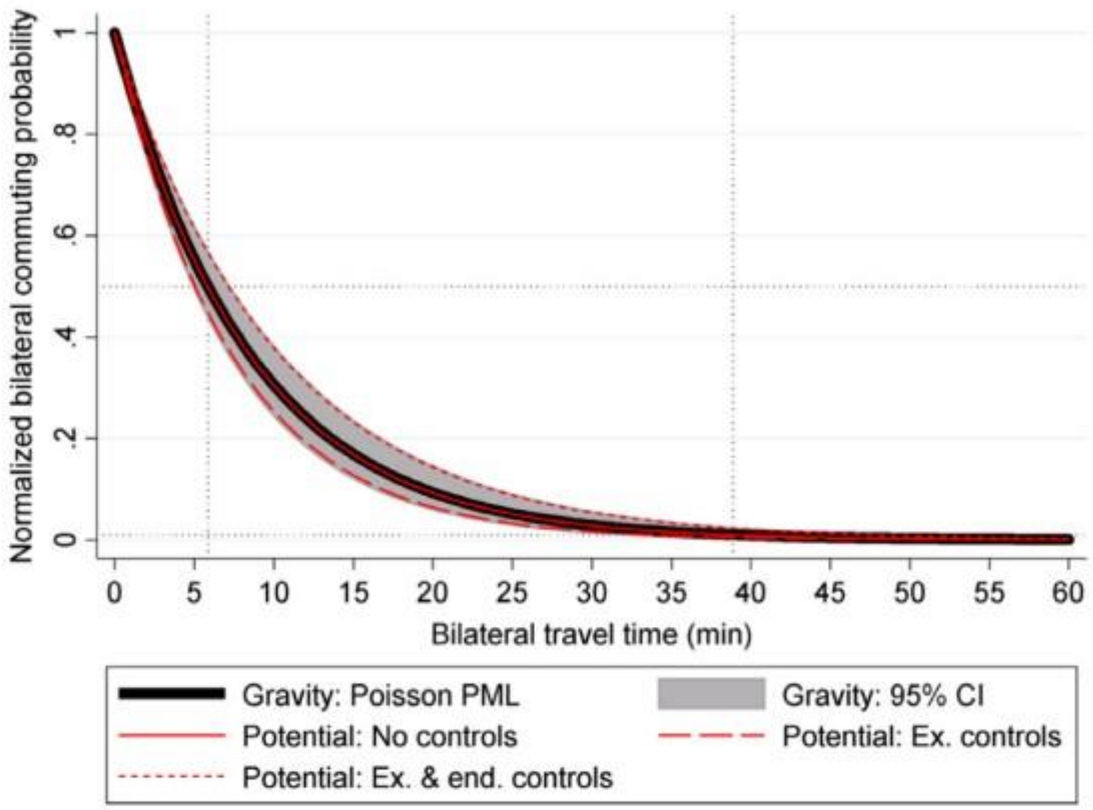


Figure 3-15 Decay parameters: Employment potential vs. commuting gravity

An individual-based approach was established by Lenormand, Huet, Gargiulo, and Deffuant (2012) to overcome the difficulty of the doubly-constrained gravity model when no complete matrix of the commuting flows was available. It was found that the single parameter of this model follows a universal law that is mainly dependent on the surface area of the geographic units. Thomas and Tutert (2013) studied the distance distribution of commuter trips in the Netherlands to assess its transferability in space and time. After the fitting process, the distribution function can be described by the following equation:

$$\ln f(d) = a_d + b_d * d^{0.4} \qquad (3\text{-}6)$$

where the coefficients a and b are calibrated by a least-square fit. The curve of frequency vs. commuting distance also exhibits a negative decay tendency as shown in Figure 3-16.

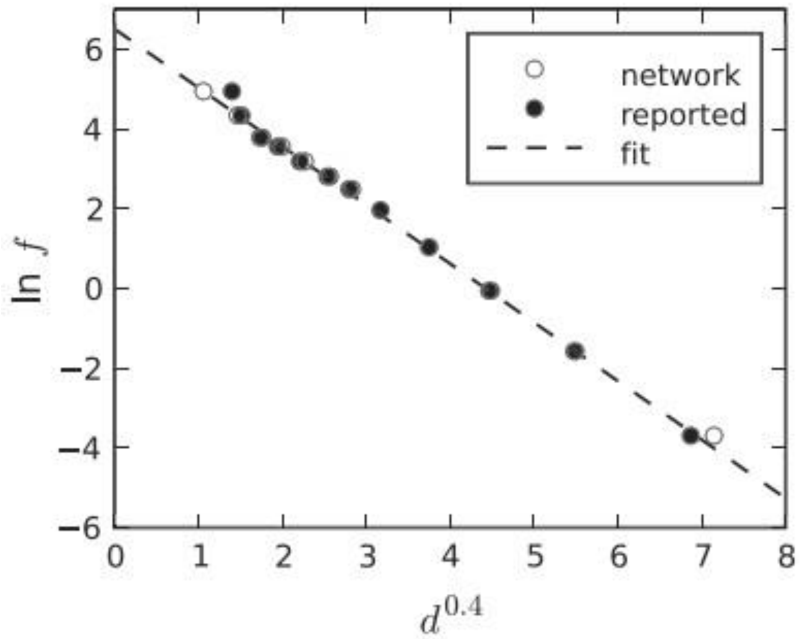


Figure 3-16 The natural logarithm of the 2006 distribution vs. travel distance

Meng (2009) chose Beijing as the case to study the spatial separation of jobs and residential locations; it was found that the imbalance of jobs-housing in Beijing has become an obvious trend entailing longer commute distances. The average commute time is around 38 minutes, and more than 43.7% of commuters spend over 40 minutes commuting. Figure 3-17 is the distribution of commuters' trip directions and volume in Beijing city area. As can be seen from the map, the inward commuter flows are the dominant commute pattern but some small-scale outward commuter flows also exist in the city centre. According to Statistics NZ (2007), the majority of commuters in New Zealand live close to their workplaces and about two-thirds of employed people live within 10 km of their workplace. Among the long distance travellers, agriculture and fishery workers travel the greatest distance, with 55% travelling 20 km or further to work.

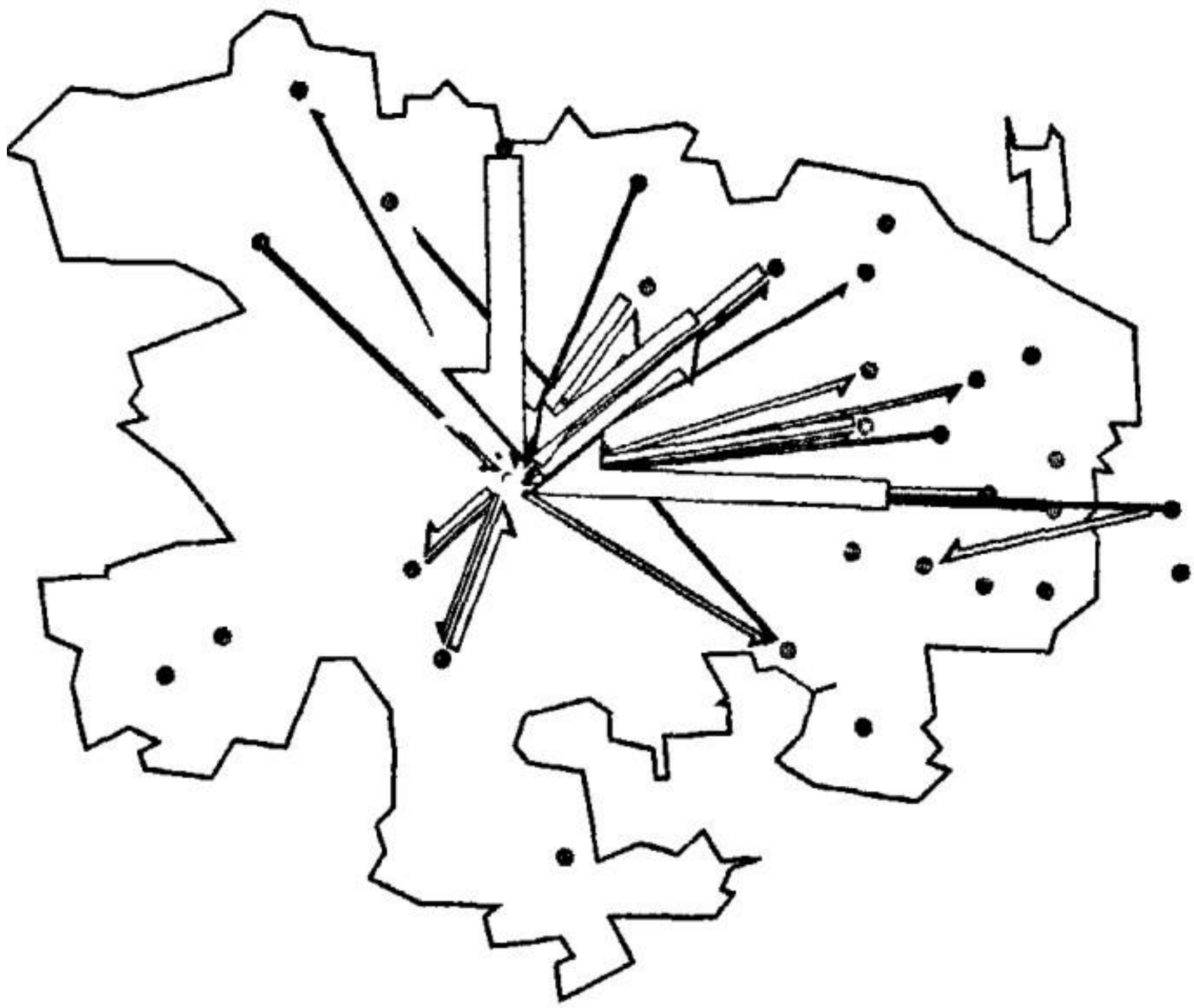


Figure 3-17 The directions and the intensities of the flow of commuters

Although these models have some strengths in simulating the commuting network, the detailed data on the amount of commuting in and out of a study region are still required for the calibration of parameters. Prior to urban planning or transport projects, a travel survey is a pragmatic method of capturing the location, distribution and mobility decision; sometimes the socio-economic situation and personal characteristics are necessary for calibration, which are costly and time-consuming (Michael, 2004). Apart from that, there are multiple parameters to be calibrated in the course of model development involving complicated computation and different variables.

3.3 Strategic analysis of complex system(SACS)

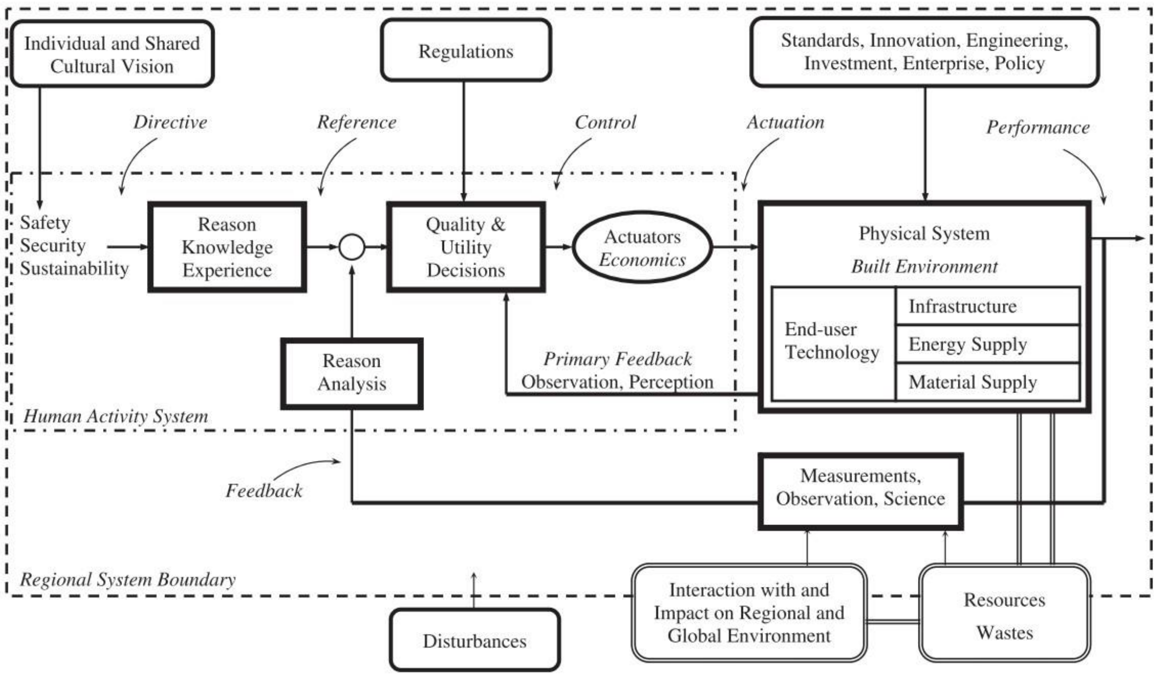


Figure 3-18 The theory of feedback control systems applied to a human activity system.

Note: Rectangular blocks are system elements; straight arrows are signals, information or actions; dashed lines indicate system boundaries; rounded blocks are influencing factors; and double lines are flows of materials or energy. The system performance is the human activity of interest, and in a sustainable system the performance meets the directive conditions of being safe, secure, and sustainable.

Krumdieck and Hamm (2009) have proposed a feedback control theory (see Figure 3-18) to describe the anthropological behaviour of a complex dynamic system in the context of environmental, economic, and social conditions. It is argued in this model that decisions are generally made on the basis of realising objectives for safety, security and sustainability. By analysing feedback signals, human decisions change with the comparison between the performance of the existing system and the desired objectives. If the system is working properly, then there is no pressure for behaviour change. Otherwise the physical environment, technology or activities are required to be adjusted or innovated to achieve quality of life. This model was applied in a study of a Peak Oil Vulnerability assessment for the city of Dunedin (Krumdieck, 2010). The study presents a comparative analysis for each development vision, as shown in the figure. A range of development options were proposed as possible methods to deal with peak oil in the future through surveys and discussion with stakeholders, including residents, council workers and business people. A target of reducing oil reduction by 2050 was defined as the exogenesis signal to trigger change projects (see Figure 3-19). The research findings showed that it does not seem possible to achieve the target by substituting biofuels or electric cars in consideration of the capacity limitation in producing sufficient biofuels and the uncertainty of electric car development. However, the behaviour adaptations, such as shopping locally, house relocation, and mode shifts to transit and active modes appear to be more promising for any urban form of development options.

Although the SACS model provides an innovative framework to analyse the vulnerability of energy constraints in different development scenarios, the practical application of this model is limited, especially in Chinese context. Moreover in transportation planning practice, the future target is usually based on the mode split structure instead of the oil supply reduction assumption. In addition, the assessment for the likelihood of each option is somewhat subjective, and a quantitative study on behaviour change under different development options, such as how people make the mode shift to bicycle are still required.

Dunedin: 50% by 2050 Oil Reduction Strategic Analysis	Urban Form Development Adaptations			
Fuel, Vehicle and Behaviour Adaptations ⇩	Active Infrastructure: 100 km bikeways to schools and shops	Dense City Centre: 50% of rural lifestyle migration to city centre	Integrated Urban Villages: 50% of shopping, education trips < 2km	Current Urban Form: No change in travel patterns
High Efficiency Fleet: 3 L/100km avg., scooters, 1 car/home	Possible Low Risk	Possible Low Risk	Possible Low Risk	Unlikely Moderate Risk
Biofuels & Synfuels: 1st and 2nd generation, crops and coal	Not Possible	Not Possible	Not Possible	Not Possible
Electric Vehicles: Imported battery cars and light utility	Not Possible	Not Possible	Unlikely *Golf carts, bikes, scooters*	Not Possible
Electric Public Bus: 50 km city lines connecting villages	Possible Low Risk	Possible Moderate Risk	Opportunity Low Risk	Unlikely High Risk
Low Carbon Lifestyle: 50% reduction private vehicle demand	Opportunity No Risk	Opportunity No Risk	Opportunity No Risk	Possible Low Risk

Figure 3-19 The Opportunity Space for Dunedin, New Zealand is shown as un-hatched areas of the Possibility Space matrix formed by laying out the urban form and infrastructure development scenarios in the columns with resource, technology and behaviour adaptation options in the rows.

Undoubtedly, the change in travel behaviour would pose risks on a traveller's activity participation. The impact of behaviour change on travel patterns may be represented by many different dimensions, including time cost, trip distance, trip frequency, personal well-being (e.g. comfort, safety), environmental gains and so forth. If the trip distance is short, the loss of time and the discomfort of forgoing car driving are relatively low. Otherwise, the commuter would suffer a long-term trip or have to relocate. Typically, in the aspect of shopping and recreation activities, the restriction on car use might result in decreased patronage, further exacerbating economic prosperity. Based on the aforementioned theory, an adaptation model under a range of development visions will be described in the following section.

Krumdieck, Page and Dantas (2010) proposed a new approach called Risk to Energy Constrained Activity-Transportation Systems assessment model (RECATS) to evaluate the risk to activity participation in the context of energy constraints. Based on the Peak Oil theory, the approach first evaluates the probability of all kinds of fuel supply in a given year, then calculates the impact of energy supply-demand imbalance on current car trips. In this research, a new measurement to classify the importance of human travel activities was proposed as Essential, Necessary and Optional respectively. It is assumed that the original car trips would be affected if the fuel supply cannot meet the expected transport energy demand. The Monte Carlo method was used to simulate the process of car trip changes by means of mode shift, distance shift, and trip combinations; all trips are assigned an essentiality weight, assuming that the essential activities exert the highest impact on residents if they are changed or lost. This model was applied in a comparative case study among three future development options for Christchurch in the year 2041, as presented in the Greater Christchurch Urban Development Strategy. The ultimate results show that the Concentrated development pattern, compared with Consolidation, Dispersal and 'Business as Usual' scenarios, has the lowest risk profile.

The RECATS model is the first strategic research on how to quantify the impact of fossil fuel constraints with new thinking about adaptation and renewal of urban forms in reaction to energy demand reduction. However, this method is an aggregate transport model for studying human adaptations in a generalised way; actually, the human adaptive capacities are heterogeneous in different travel activities. Furthermore, the spatial distribution of transport adaptation risks at the region level cannot be observed with this method. In addition, the specific instruments or operations that can reduce the risks need to be further refined.

3.4 Transport adaptation

Within an interactive urban transport system, people could adjust their travel behaviour to meet their trip purposes and participate in economic activities when land use, transport network or socioeconomic conditions are changed. For a car driver, if they could access as many as places by alternative travel modes without wasting too much time, they would have a high adaptive capacity under the condition of energy constraints. For a city or city area, if the majority of activities could be accomplished efficiently without using private cars, its potential in low carbon travel is of high value for achieving sustainable development. Living in this area, people's living and trips would not be severely affected given policies, such as restrictions on car driving to reduce congestion and mitigate CO_2 emissions.

According to Krumdieck et al. (2010), there are three adaptation methods to reduce the transport energy intensity of travel to engage in an activity:

- Combining travel to multiple activities into a single trip chain;

- Using a more efficient vehicle or shifting to a less energy intensive mode;
- Selecting activity destinations or housing locations that require less travel, including participating without travel.

If none of the above methods can be adopted for an activity, the participation in that activity may have to be forgone.

Wegner and Fürst (1999) established the process of urban changes, which are differential in the physical environment and human behaviour. People and firms have higher adaptive capacity in response to exogenous pressures or changes by modifying their mode choices or locations, compared to the slow changes in the physical environment. Travellers are prone to minimise travel costs and travel times, and shoppers are more likely to reduce their trip frequencies to faraway destinations rather than switching to closer destinations (Ampt and Rooney, 1998).

Stacy developed a METE model to calculate the minimum transport energy consumption in order to meet day-to-day travel requirements assuming each individual chooses the viable minimum energy-intensity travel mode within their time budget for different trip purposes. This study is the first analysis methodology for mapping the spatial distribution of limits to transport energy adaptive capacity. However, the METE model was built on the basis of New Zealand situations, and it is seemingly not applicable to a Chinese context due to the differences in national conditions and the disparities in travel survey methods. Furthermore, the METE model is a disaggregate method for detecting the spatial distribution of adaptive capacity for each resident, which probably leads to a massive computational load when the population is very large.

4. Research methods overview

The AEMS (Advanced Energy & Material System) Lab has developed a range of measurements and tools to explore the adaptable capacity of urban form development in response to fossil fuel shortages; however, these models might not be applicable in the Chinese context in view of the differences in the national situation and the travel survey design. Therefore, some modifications in previously developed models are required to enhance their applicability and to practise their implications across the world. Following the rationale of Transition Engineering, the CUTEAAP model is constructed upon approaches of data collection and analysis, travel activity modelling, strategic analysis and adaptation modelling. This chapter briefly introduces the methods used in this study, the detailed description of which will be expanded in the following sections and case studies.

4.1 The rationale of transition engineering

When a new opportunity or a new issue arises throughout human history, a new field of engineering emerges to make use of the opportunity or resolve related problems. For the past several hundred years, a number of engineering methods have been developed to help extract and exploit natural resources, extend human capabilities in communication, computing, medical treatment, warfare and so forth (Krumdieck, 2011). Meanwhile, the adverse impacts produced by these beneficial activities also pose huge risks for people’s sustainable development. In a sense, the technological innovations are instrumental in alleviating these unintended consequences, such as the development of catalytic converters and particulate scrubbers in response to the health risk of lead exposure and urban smog. However, the most wicked problems people are confronting across the world, in consideration of the reduction of fossil fuel and climate change, require up-stream changes to the system, infrastructure and human behaviour, and these changes need to be part of economic development. Transition Engineering is emerging as a field that achieves a sustainable balance between the risks and benefits of human activity by innovating, designing, and implementing changes in existing systems. Transition engineering is not a discussion about real solutions that are currently employed in practice at a known cost and with a known performance; instead, it is centred on how to reduce the risk of unsustainable energy use, resource consumption and environmental impacts and explore low-carbon potentials and big shifts in development away from unsustainable activities. Idealistically, a transition project can change an existing system to one that does not require fossil fuel or unsustainable activities and unacceptable impacts while maintaining economic growth and activity participation in the course of development. Krumdieck (2012) has proposed a transition engineering framework for working on wicked problems in complex systems, as illustrated Figure

4-1.

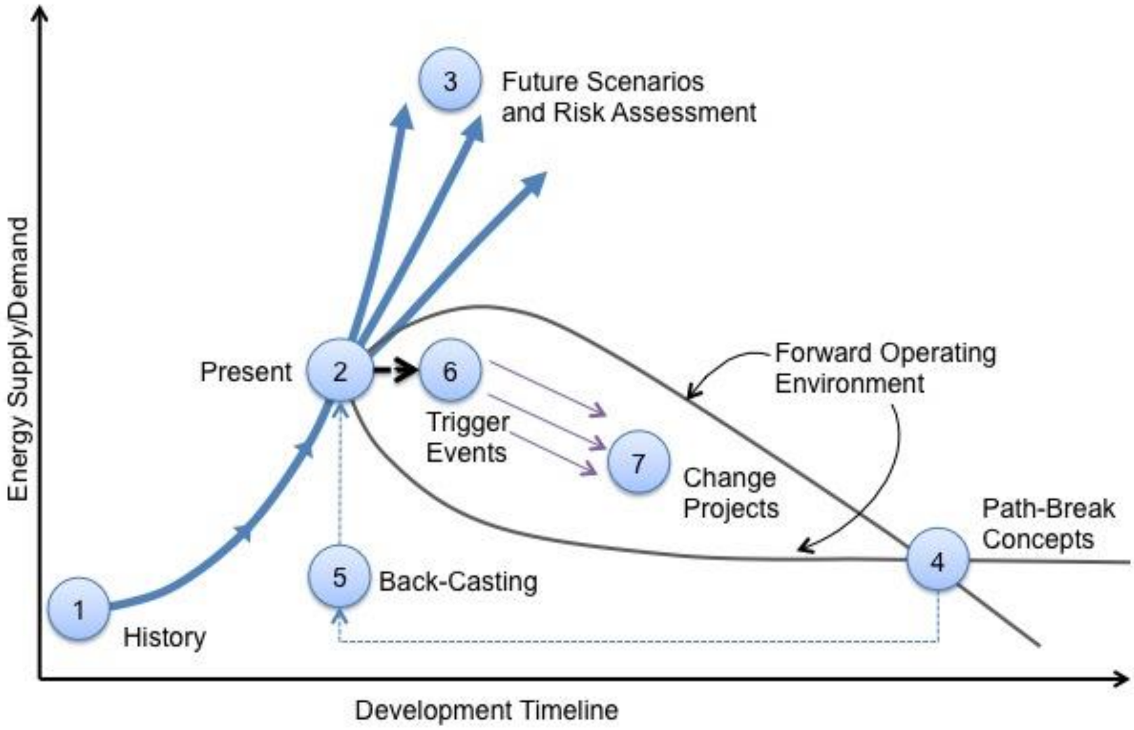


Figure 4-1 Framework of Transition Engineering

Firstly, the investigation about historical trends and the current situation are required to understand where the problems are, and how they have developed. Then a few scenarios are developed to identify which future trends have unsustainable risks of keeping the business as usual without remedial changes. The fourth step is a brainstorming process where path-break conceptions are generated on the basis of resource availability and engineering feasibility. Thereafter, the difference between the innovative path-break vision and the current system can be identified through the back-casting procedure. The trigger events might be an urgent crisis or a policy objective that initiate future transition projects. Finally, the transition projects are implemented with the new ideas, new standards and new business opportunities developed around the trigger events.

The aforementioned is the generic description of transition engineering methodology; in practice, there are a variety of mature engineering tools that can be borrowed to implement the transition engineering process, especially for steps 1, 2, 3. However, the main interest of our research is to identify issues, assess risks, plan for changes, manage projects, and monitor performance. In this connection, the next section presents some critical analysis tools to describe the application of transition engineering to a transportation system.

4.2 Data collection and analysis

Data collection and travel surveys are indispensable steps for transport research. Generally speaking, the required data in a traditional transport framework include household travel surveys, workplace surveys, stated preference surveys, longitudinal surveys and so forth, with various forms involving physical, geographical and socioeconomic factors. However, conducting surveys is a time-consuming and costly task with only a small fraction of the population being involved. Also, it is not unusual that the data collection methods in a country are not interoperable in other countries. To overcome these difficulties and for the sake of simplification, only a few easy-to-catch data are considered in this research to construct the consequent models. All of these data basically are tangible and measurable variables that can be readily obtained in various countries; the socioeconomic factors, such as personal attributes and individual preferences are excluded from this research. Based on the available data, an essentiality-weighted shopping activity model and a distance-resolved commute model were developed respectively to characterise the current travel patterns of Beijing, whereby the users can analyse the low carbon potentials without too much need for travel surveys.

All the GIS data about Beijing were acquired from Siwei Mapping Limited Corporation, including residential quarters, workplaces, shopping facilities, road networks, and transit systems. Each facility consists of a series of fields based on its attributes. For example, the shopping facilities are divided into 25 categories in terms of scale and commodity. Apart from that, the demography data and employment opportunity data were extracted from government statistics.

4.3 Travel activity modelling

Due to the limitations of data regarding the present travel surveys on shopping activities and work trips in Beijing, some conventional transport activity modelling approaches are used to characterise the current travel patterns, thereby laying a mathematical foundation for the following adaptional analysis.

4.3.1 Modelling present shopping activities

By incorporating the essentiality theory into the Huff model, a popular method to quantify the spatial interaction between consumers and shopping facilities, a new shopping model was developed in this study.

4.3.2 Modelling present commute trip distribution

Aiming to unravel the universal law governing human commuting distance distribution, the commute model in this research was conducted by a Data fitting process and regression analysis with only one parameter to be determined.

4.4 Key analysis tools

4.3.1 Strategic analysis of transportation systems (SATS)

Before starting the strategic analysis, the system being studied must be defined, characterised or simulated with a standard engineering model. After setting the development goals, the strategic analysis is conducted according to the following steps:

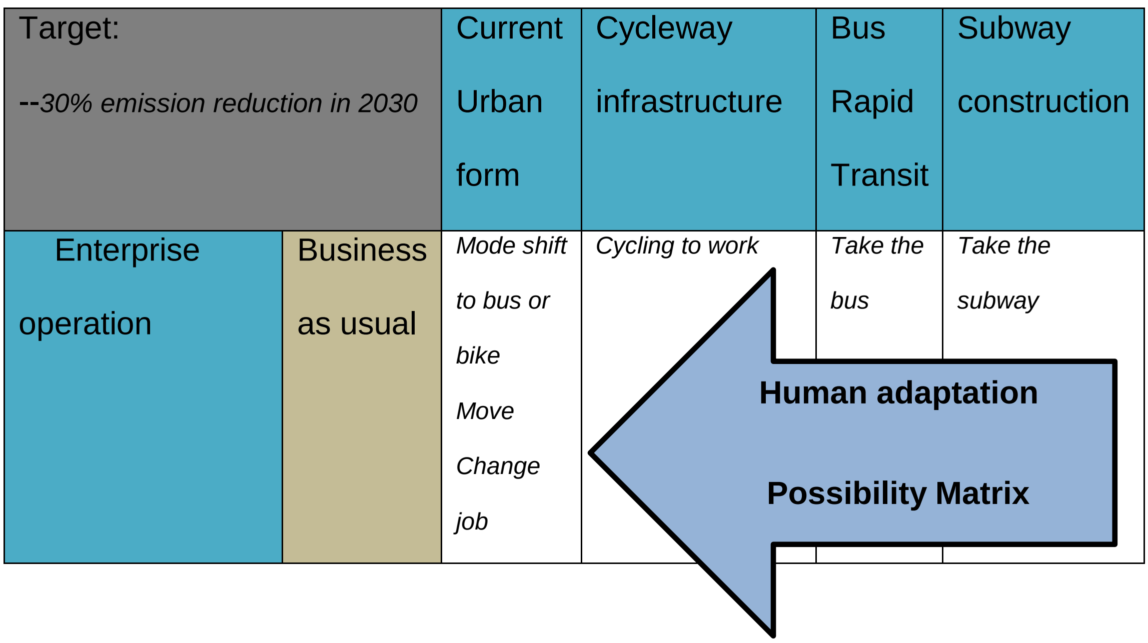
- Development options generation. Future possible development scenarios can be obtained through government master plans, participatory methods, and surveys. The development options can be separated according to the attributes of development, say the physical system changes (infrastructure, urban form, and transport system) along the columns, and the policies or technologies changes along the rows.
- List a series of possible individual behaviour changes under different development scenarios to form the possibility space. Some obviously impracticable options might have to be eliminated.
- Assign the proportion to each behaviour change choice to form a combination of feasible options until the target is achieved. The proportion can be randomly assigned or set as appropriate.
- Calculate the risk of each combination of behaviour changes in the context of development scenarios. Assess the relative costs of each feasible option, including infrastructure cost, operation cost, and personalised cost, which can be designated by a number of dollar signs in the cells (see Figure 5).

- Assess the possibility of reaching the target for each combination of behaviour changes based on the surveys, social values and conditions. The possibilities might be ranked as: likely, possible, unlikely, or no possibility.
- Rank the overall risks to activity participation and the cost of changes once the target is achieved, say using the following colours:
    - **Green.** Low Cost, No Motorisation Required, Low Risk, Renewable Resources, Recyclable, Long Life, Enhances Learning, Improves Community, Improves Health
    - **Yellow.** Affordable, Medium Motorisation Required, Moderate Risk, Limited use of Finite Resources, Reusable, No Negative Social Impacts
    - **Red.** High Cost, High Motorisation Required, High Risk, Does not improve Health, Does not fit with Social Values
- Use the resultant opportunity space to communicate which development scenarios and behaviour changes could represent the possible development paths to meet the development goals.

A communication tool representing human travel behaviour options under different development scenarios is exemplified in Figure 4-2. A target of reducing 30% carbon emission by 2030 has been established prior to the analysis. A range of development visions for physical environment changes, such as urban planning and transport system improvements are enumerated in a row. Meanwhile, some ‘soft’ changes from the destination side, such as work unit provision or shuttle service are listed in a column. A matrix of possible human adaptation options with respect to the changed external signals is presented. For instance, currently, travellers have a number of alternative choices to reduce motorised trips: if the commute distance is short, some commuters can walk or cycle to work. If the commute distance is long, some commuters may move closer to their workplaces, and a few commuters might have to change their jobs. Furthermore, if some large-scale enterprises can provide or help rent a closer apartment for their employees, more employees would like to move to the apartment, increasing the possibility of walk and cycle mode sharing.

Figure 4-3 is a schematic illustration communicating the comprehensive score for each adaptation combination with regard to the possibility, cost, impact and so forth in order to achieve the target. In this figure, it seems that to some extent the cycleway infrastructure is in favour of carbon emission mitigation. The work unit design appears to be such that it makes the most of the development scenarios' viable opportunities, but a number of investments and costs are still required as a result.

The detailed operational description of the aforementioned approaches is further explained in Chapter 10.



	Work unit provision	*Move to the work unit*	*Move to work unit*	*Take the bus Move to work unit*	*Take the subway Move to work unit*
	Shuttle service	*Take the shuttle bus*	*Cycle to work Take the shuttle bus*	*Take shuttle bus*	*Take shuttle bus Take subway*
Shopping facility operation	Business as usual	*Mode shift Change to closer shops*	*Cycling to shop*	*Take the BRT*	*Take subway*
	Shuttle service	*Take the shuttle bus*	*Take the shuttle service*	*Take the shuttle Take the BRT*	*Take the shuttle service Take subway*
	Online shopping	*Shop at home*	*Shop at home*	*Shop at home*	*Shop at home*

Figure 4-2. Illustration of development scenarios and human adaptation options

Target: -- *30% emission reduction in 2030*		Current Urban form	Cycleway infra-structure	Bus Rapid Transit	Subway construction
Enterprise operation	Business as usual	No possibility $	Possible $	Likely $$	Likely $$$$
	Work unit provision	Likely $$$	Likely $$	Likely $$	Likely $$$$

	Shuttle service	Possible $	Likely $$	Likely $$$	Likely $$$
Shopping facility operation	Business as usual	No possbility $	Possible $	Likely $$	Likely $$$
	Shuttle service	Possible $	Likely $$$	Likely $$$	Likely $$$$
	Online shopping	Likely $			

Figure 4-3. Comprehensive comparison in different development schemes

4.3.2 Adaptation model

There are a variety of ways to accomplish objectives; however, to a great extent the built environment determines the range of behaviour options. For example, an urban transport system is a typical complex system with an entangled connection among man-vehicle-environment. The spatial structure of urban form (e.g. the employment distribution) has a crucial impact on the jobs-housing balance, mode choices and travel patterns. Usually segregated land use might lead to heavy automobile dependence (Bruegmann, 2005; Hayden, 2003), commuters living in work units are more likely to commute by walking and cycling (Wang & Chai, 2009), and a dedicated cycleway could increase the possibility of travel by bike (Zhao,2014). It follows that human beings can change their travel patterns to fit the surrounding environment.

In order to solve issues in urban transport systems, the government sets transport policies aimed at reaching a development goal or target in a given timeframe. In response to the external directives, society, individuals and organisations have to adapt their operation patterns to the changed environment. Basically there are a range of car-driving adaptation options with multiple dimensions of change:

- **Transport mode choice**. For example, travellers can walk or cycle to work if the trip distance is viable for the active mode, or they can take transit for long-distance trips.
- **Origin and destination choice**. For example, commuters can move closer to their workplaces if affordable housing is available, or change their jobs to closer ones.
- **Urban Form, and cycling and transit infrastructure** to attract car drivers to change their travel patterns.
- **Property and land use changes** to shorten travel distances.

In addition, some convenience service from the trip destination side, such as the shuttle bus service from the shopping mall, a staff apartment nearby, online meetings or shopping can also reduce the probability of car trips.

Based on the rationale of Transition Engineering, the upcoming chapters from 5-10 will present respectively according to the steps of the Transition Engineering framework (see Figure 4-1). The other methods as described above will be explained in more detail in specific chapters.

5. The historical development of urban transport systems in China

Prior to analysing the studied system, the first step is to understand the system dynamics by looking into the history and past behaviour. All information and facts about historical urban form development and transport system changes are required. This chapter reviews the historical development of urban China after 1949, and presents the characteristics of the transport system in Chinese cities. The previously dominant urban form——The Work Unit (Danwei) system receives more attention in this chapter to demonstrate its significance in sustainable development for China.

5.1 The evolution of urban China (Work unit)

Different from western cities, Chinese cities have their own characteristics because of their unique history and institutional backgrounds, such as the socialist legacy of the work unit (Danwei) system and less segregated land uses (Wang, 2011). A typical big Chinese city is represented by a mixed-use central core area with a radius of around 5 km where there are large numbers of jobs and densely populated residential communities. The city centre is surrounded by the suburban area consisting of largely residential areas developed along radial corridors, as shown in Figure 5-1.

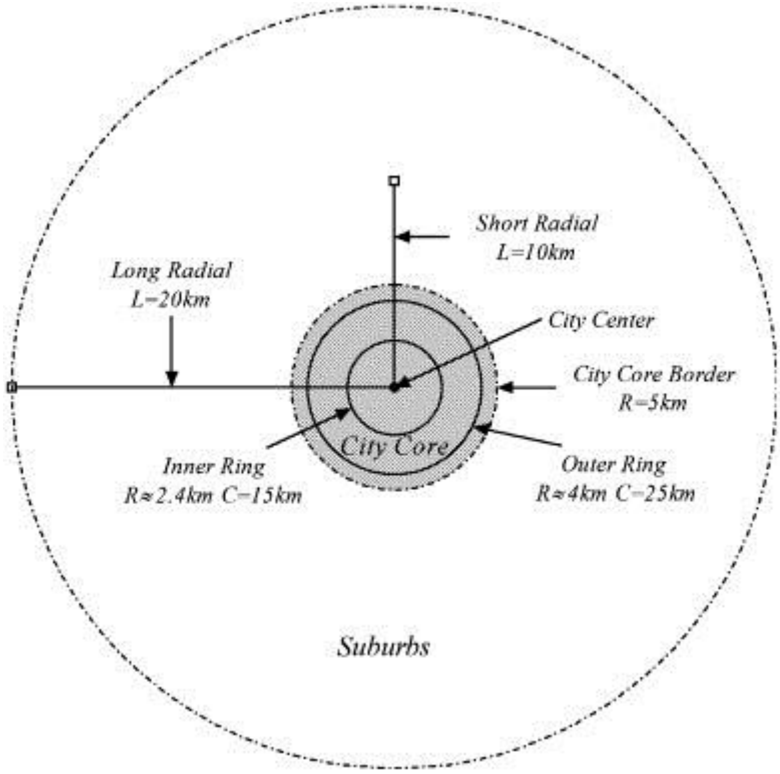


Figure 5-1 Representative large Chinese city and corridors (Wang, 2011)

After the founding of the People's Republic of China in 1949, China began to adopt a new urban development pattern—the Work unit (Danwei)—which has a resemblance to the Soviet Union's socialist urbanism. Originally it was according to classic Marxist theory, where the socialisation of human life is an essential characteristic of socialist society. In this society, the community is responsible for the allocation of property, including job, food, welfare and living services. In the context of a central-planned economy, the state-owned enterprise is responsible for the basic necessities of workers, including housing, jobs, education and medical services. Accordingly, each work unit has multi-functions of not only production but also residence and social welfare (Chai, 2014). The work unit in China emerged as a specific response to the problems of resource allocation, production organisation and social governance (Liu

2000; He, 2003). Wherever property acquisition can accommodate it, the workplace becomes the principal unit around which domestic and social activities are linked; Danwei has become a term used to signify this spatial integration of work, residence, and social life in cities organised by the Communist Party of China (CPC) (Bjorklund, 1986).

Prior to the economic reform starting in 1978, the work unit form had been pervasive in nearly every Chinese city as the basic organisation cell to manage employees' daily life in consideration of the problems of resource allocation, production organisation and social governance (Liu 2000; He, 2003). It was not only an economic organisation for industrial production, but also a rigid political hierarchy to avoid social chaos and free migration. Lü and Perry (1997) argued that as a basic unit in the CPC political order, the work unit is a mechanism with which the state controls members of the cadre ranks, monitors ordinary citizens and carries out its policies. Once one had an opportunity to work as a formal employee in a state-owned factory, it meant that the essential living needs, including job, housing and medical care would be guaranteed, which was deemed as a stable social status without too many concerns for subsistence. In particular, the work unit assumed the full responsibility of housing provision for its employees; this system left the employees no choice but to live in houses allocated by their affiliated Danwei, because there was virtually no housing market from which one might buy or rent a house (Wang & Chai, 2009).

In the aspect of spatial structure, it is represented by 'small and all-inclusive' functions comprising a variety of facilities and social services within walkable or cyclable distances. The most important feature of the work unit consists in the localised residence around the administrative area of the enterprise or as close to the working place as possible (see Figure 5-2). Living in the work unit allocated by the enterprises, employees can shop in local grain stores or eat in staff canteens, go to work by walking or riding a bicycle, send their children to kindergarten or school, enjoy free medical treatment in the local hospital and so forth. However, this urban form left the employees no choice but to live in the staff apartments because there was virtually no housing market from which one might buy or rent a house outside the workplace (Wang & Chai, 2009). Generally speaking, the features of the work unit could be summarised as follows:

- **Localised employment** (or residence). The living spaces are usually built in the administrative area of the factory or as close to the workplace as possible.
- **Multifunctional layout with high density**. For each work unit, the basic living requirements (e.g. shopping, hospitality, education, recreation, hospital) could be accessible within a short distance.
- **Enclosed or semi-enclosed community**. The transport infrastructure in the work unit is represented by streets, walkways or local roads with low speed limitations.

Figure 5-2. A 1 km × 1 km sketch of a classical work unit design in China

(Source: modified from Lin (2014))

With the rapid progress toward a market-oriented economy and Chinese urbanisation, the work unit is gradually losing its dominance. After the housing reforms since 1998, in principle all state-owned enterprises in China never build staff apartments; also, the majority of affiliated facilities, including schools, hospitals and parks either have become independent or are consigned to local city councils for governance. While the commercial residential community is emerging with social transformation and urbanisation in China, more and more people have to relocate to suburban areas for affordable housing opportunities due to the high housing prices in the city centres, which results in a job-housing imbalance and a long-distance commute (Zhou et al., 2014). Figure 5-3 shows the geographical distribution of commercial housing in Beijing with the ring roads of Beijing highlighted. Nevertheless, the legacy of the work unit is still visible in China’s big cities; for example, there are nearly 2000 work units around the city centre of Beijing (see Figure 5-4).

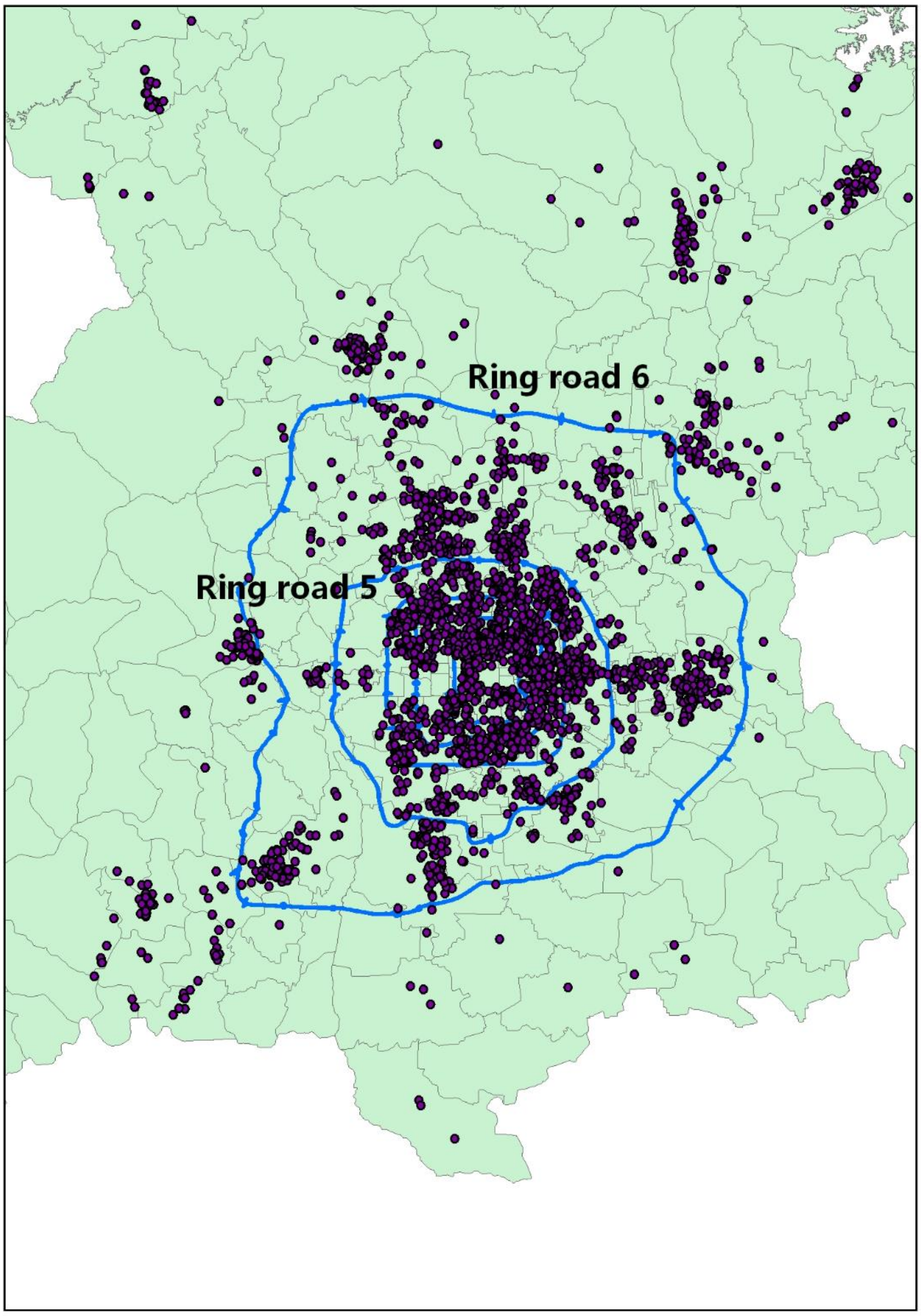


Figure 5-3 Commercial Housing distribution in Beijing

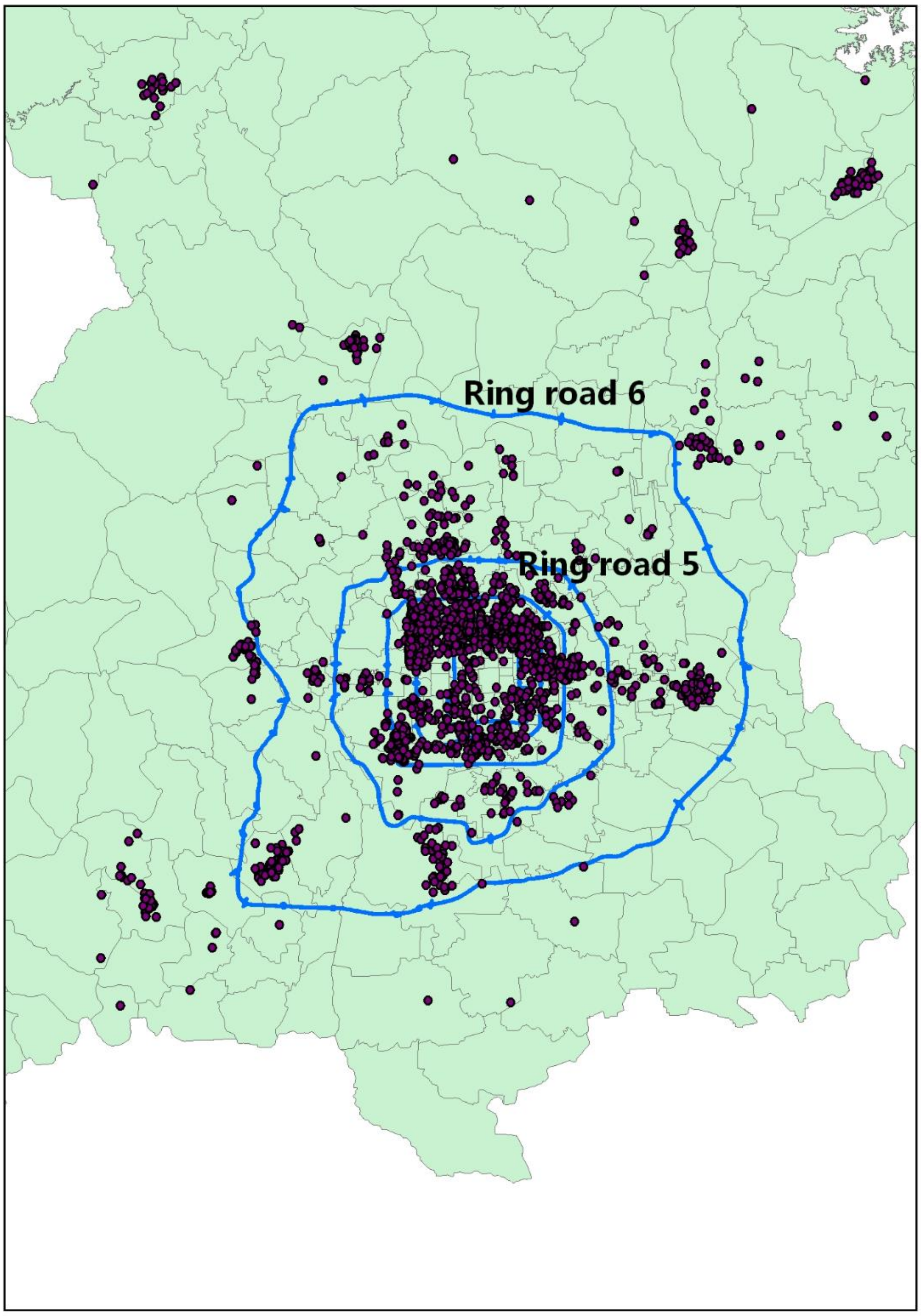


Figure 5-4 Current Work Unit distribution in Beijing

Based on the travel survey data of Beijing residents in 2007, Liu, Zhang and Chai (2009) made an investigation of commuters' travel patterns in different dwelling types and calculated the Euclidean distance between their working places and living places. The comparison of commuting distance is shown in Table 5-1. It can be seen that the work unit has significant advantages in short distance work trips with the average commuting distance for a work unit being only 3.9 km, and nearly half of the residents living in work units could commute by walking or bicycle. Therefore, the possibility of using motorised travel mode for commuting is supposed to be lower for the work unit, which was testified to by the research findings of Zhang and Chai (2009) (see Table 5-2). Around 70% of residents living in work units go to work by walking or bike, whereas the commercial housing option might lead to a higher car trip share. Accordingly, in terms of work trips, the work unit has obviously low carbon travel potential in comparison to the non-work unit.

Table 5-1 Commuting distance comparison by dwelling type

Dwelling Type	**Mean commuting distance** (km)	**50 percentile value** (km)	**Standard Deviation**
Work Unit	3.9	1.3	5.6
Commercial Housing	7.2	5.4	7.6
State Apartment	10.1	9.6	8.5

Table 5-2 Travel mode split by dwelling type

Dwelling Type	**Total trips**	**Travel mode split (%)**		
		Walking and bike	**Transit**	**Car**
Work unit	8.11	67.43	18.75	13.83
State apartment	7.74	58.50	21.55	19.95
Commercial housing	7.14	52.70	23.75	23.55
Total	7.90	64.71	19.59	15.70

Chai et al. (2011) carried out a travel survey about carbon emissions of inhabitants' daily travel behaviour from work unit groups and non-work unit groups. The research findings provide evidence that the travel patterns in work units have a lower carbon potential. Table 5-3 shows the variation of the modal split among different dwelling types. It can be seen that the work unit has the lowest car use share and highest active mode share. The reason why the work unit has more trips is: 1) Most residents in work units are closer to their workplaces; they usually go home for lunch or take a rest then come back again, hence adding more commute trips. 2) The proportion of retired people living in work units is higher, leading to more resilient trips like shopping, recreation, fitness and exercise.

Table 5-3 Travel pattern comparison in different dwelling types

Neighbourhood type	**Total trips**	**Travel mode split (%)**		
		Walking and bike	Transit	Car
Work unit	8.11	67.43	18.75	13.83
State apartment	7.74	58.50	21.55	19.95
Commercial housing	7.14	52.70	23.75	23.55
Total	7.90	64.71	19.59	15.70

Figure 5-5 shows that the work unit still has shorter trip distances, especially in the aspect of commuter trips. The state apartment has the longest commuter distance due to the imbalance of jobs-housing distribution. Likewise, the absence of shopping facilities around state apartments give rise to a longer shopping distance as well.

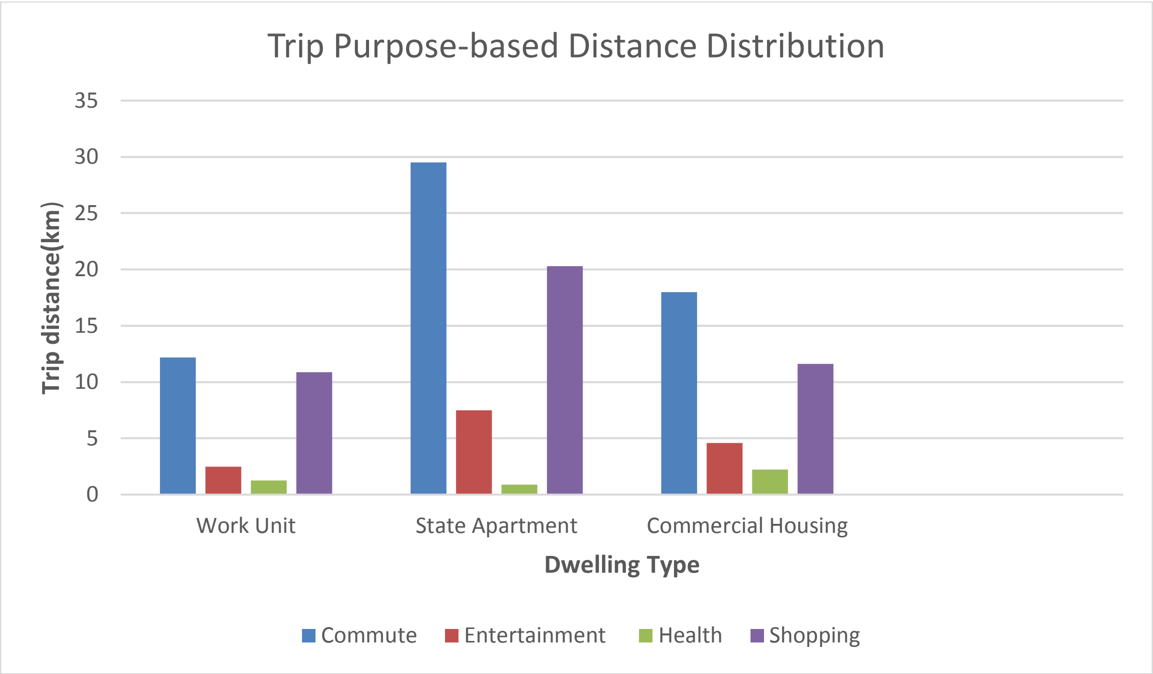


Figure 5-5 Trip distance comparison by trip purpose

5.2 Transport system of China

In Chinese cities, the road transport system is divided into five technical grades:

- **Freeway**: speed range (80-120 km/h)
- **Ⅰ class road**: National road or arterial road. Speed range (60-100 km/h)
- **Ⅱ class road**: speed range (60-80 km/h)
- **Ⅲ class road**: speed range (30-40 km/h)
- **Ⅳ class road**: speed range (20-30 km/h)

Except for freeways and National roads, almost all the road networks could accommodate shared travel modes, resulting in a serious interference from motorised vehicles, non-motorised vehicles and pedestrians. Figure 5-5 shows a classic image of busy traffic with mixed travel modes in China’s cities. Figure 5-6 is a scene from the local transport system in a Chinese work unit.

Figure 5-6 A classic shared-use road transport infrastructure in China

Figure 5-7 A typical local transport system in Chinese work unit

For a long period, China has been a country with low levels of motorised transportation and it has even been called the ‘the kingdom of bicycles’. At present bicycles are still commonly used almost everywhere in China although automobile ownership has risen sharply in recent years. Commonly used road transportation means in China include:

Bicycle: Despite the fast growth in car ownership, the bicycle still remains the primary means of individual travel within a city for many Chinese people. However, a number of transportation planners, governed by the auto preference policies, have developed the misconception that to realise modernisation in the transportation system, bicycles have to be eliminated (Guan & Liu，2005). Prior to rapid motorisation, a large number of urban streets in China were designed for bicycling. It is still common to see more and wider bicycle lanes than motor vehicle lanes in some cities. However, the motorisation and auto preference policy changed all that. A number of cities have totally removed bicycle lanes and others have been significantly reduced.

Electric bicycle: Electric bicycles are a very popular form of transportation used almost everywhere, especially by low and medium income households. There are two types of electric bicycles in China: one is the bicycle-style electric bike propelled by human pedal power with supplementary battery and motor; the other is the scooter-style electric bicycle propelled by electricity only. It is estimated that electric bicycles account for 10 - 20% of all two-wheeled vehicles on the streets of many cities in China. By charging about 8 hours they can run a distance of 25-30 miles at a speed of 20-35 km/h (IEEE Spectrum, 2005). If technically improved and positively encouraged, electric bicycles with higher speeds and more comfort could gradually substitute for pedal power bicycles and even private cars over the next decades. Although some national electric bicycle standards and road rules were regulated in 1999 and 2004, local governments have the authority to enforce these rules and manage traffic (Weinert et al., 2007). Some cities such as Shanghai and Chengdu favour the use of electric bicycles to mitigate air pollution and control gasoline scooters. Other cities such as Beijing banned the use of electric bicycles at the beginning due to their effects on reducing traffic speeds, and increasing safety hazards in mixed bike and car traffic. However, eventually local governments cannot resist the fact that more and more electric bikes are being used. Recent observations in Beijing show cycle lanes are being reinstated.

Public Bus: The bus is the most extensive and affordable transportation tool in Chinese cities. Some big cities, such as Beijing, offer an extremely low pricing system to encourage more travel by bus.

Metro and rail transit: Currently there are 15 rapid transit systems in China. A further 18 systems are under construction and 20 more metros are planned. Although fully supported by the government in terms of finance and policy, the metros in Beijing seemingly fail to alleviate the troubles in congestion and overcrowding.

Private car: Personal vehicles are an increasing mode share along with massive urbanisation and urban sprawl. In the context of China, owning a car sometimes means higher social status rather than a real necessity. The profusion of cars has transformed Chinese life and society in ways that bear surprising resemblance to what happened in America 50 years ago (Chandler, 2003), which is characterised by severe traffic congestion and air pollution.

According to BJTRC (2015), the bike mode share for work trips in Beijing has declined from 62.7% in 1986 to 12.6% in 2014 (see Figure 5-8), whereas the car mode share has gradually increased peaking at 34.2% in 2010 and then slightly dropped down owing to the implementation of car use restriction policies by the municipal government of Beijing since 2009.

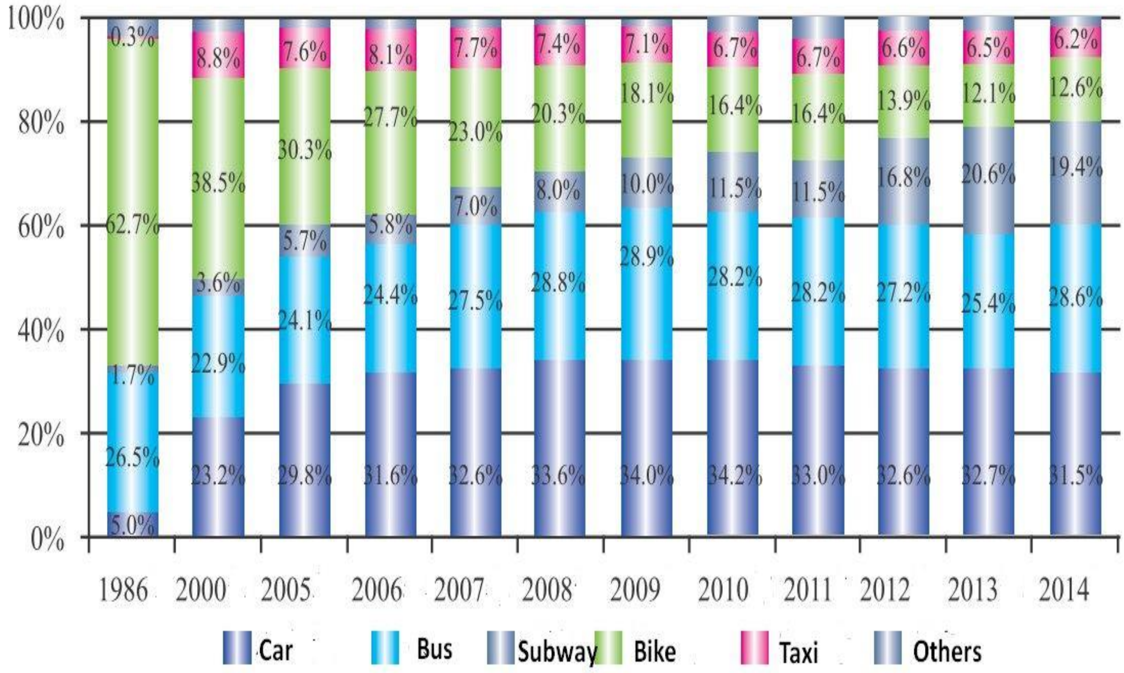


Figure 5-8 Historical trend of travel mode split in Beijing

5.3 Implications of work unit design for future sustainable development in China

Theoretically, it might be inevitable that the market economy encourages more freedom in the migration of production factors, including capital, resources, technology and labour force. However, the blindness of market power and the disorder in economic transition will result in excessive energy use and random expansion, which would in turn deteriorate environmental protection and social harmony. Being a legacy of a centrally-planned economy, the work unit, as described above, also supports the view that more balanced jobs-housing relationships may lead to shorter commuting trips, increased the usage of non-motorised transport mode, and reduced travel, which may imply less energy consumption and less emission of air pollution (Cervero, 1989). Therefore, developing an urban form with work unit design to realise the balance between development and energy constraints would be significant to cope with future possible peak oil or energy shortages.

High Active Mode Accessibility (AMA): AMA is defined by Rendall (2012) as the proportion of activities that can be accessed by human-powered transportation (such as walking, running and cycling). It is obvious that AMA is negatively related to oil use, an urban transportation system with higher AMA is less reliant on oil for transportation. As can be seen from the literature mentioned above, in the case of the work unit, the shorter distance coverage and all-inclusive micro-facilities also make it more accessible by active modes.

Multifunctional land use： Until recently, some work units still assume the responsibility for the procurement of welfare including some food and daily necessities for employees. In addition, some collective living facilities, such as factory canteens, leisure squares and retirement centres bring certain convenience for local inhabitants. It is believed that with the improvement in living quality and progress in society, more advanced requirements would not be locally satisfying, and, as a consequence, the interaction with outside places would become more frequent presumably resulting in more energy use. However, this pattern of compact development, associated with the supply of necessities, still retains enormous potential to achieve energy conservation and harmonious growth.

Internal mobility: Compared to the growing urban mobility, the daily commute in the Danwei community is always ‘static’ with no energy consumption (Chen, Zhu &

Ren, 2012). In general, the vast majority of essential activities can be performed within the area of the work unit, which leads to a higher AMA at local level and less mobility towards other destinations outside.

6. Characterisation of present transport energy performance

In order to understand the current urban transport system, some audits and end-use demand assessments are required for quantitative analysis. In reality, however, sometimes it is very difficult to obtain first-hand data due to confidentiality issues or certain constraints. Based on the available data, taking shopping activity and commute activity as examples respectively, this chapter proposes some new metrics and models to characterise current travel activities in the absence of empirical data or sufficient travel surveys.

6.1 Modelling shopping activity

Owing to the lack of travel survey data, a modified Huff model taking account of shopping hierarchy was developed as the baseline for the following adaptation analysis.

6.1.1 Terms and Definitions

There is no commonly accepted definition about the shopping hierarchy. Basically it is a concept that classifies and ranks the level of shopping services. There are a number of factors contributing to the ranking of shopping services in a region, such as the order of goods, population flow, accessibility level, travel cost, and floor space. Some ‘convenience’ goods, such as food, drink and beverage, are frequently purchased goods without the need to occupy a large space because they are not expensive and do not require shoppers to travel longer distances (Jill, 2011). However, some ‘comparison’ goods, like furniture, household appliances, and jewellery, are infrequently purchased goods with a large market area because they are expensive, bulky and require shoppers to travel longer distances. The majority of daily essentials can be bought in supermarkets, department stores or regional shopping centres but sometimes they are found at neighbourhood stores owing to the need of the business to capture a greater market share (Jill, 2011). According to electronic transactions data in New Zealand (MarketView Ltd, 2011), food and beverage are found to be the largest categories of expenditure (32%), followed by the ‘comparison’ goods (21%), such as household appliances, clothing, and footwear.

It is revealed by surveys of travel behaviour that people rate as ’unnecessary’ or ‘discretionary’ as many as 30% of their trips (Gordon et al.,1988; Cevero & Radisch, 1996; Banister et al.,1997). Krumdieck, Page and Dantas (2010) quantified the relative importance of each trip for choosing which trips to take and which activities are preferable. The ‘essentiality theory’ was proposed to categorise transportation activities in the context of energy constraint, the essence of which is to decide whether trips represent an essential, necessary, or optional contribution to their wellbeing, socio-economic connection and happiness.

6.1.1.1 Shopping hierarchy

Based on these literature reviews, shopping performance was categorised as follows (Table 6-1):

Table 6-1. Shopping activity classification

Hierarchy		Definition	Example	Essentiality
Food Shopping		Required to meet basic needs of nutrition at a rate to sustain healthy calorific intake.	Food, beverage, fruit	Essential
Non-Food Shopping	Core retail	Required to meet basic needs of health and protection from elements, or for daily use	Clothing, Household appliances, shoes	Necessary
	others	Required to meet the needs of culture, spirit and lifestyle or personal tastes	Jewellery, books, photographs, cosmetics	Optional

6.1.1.2 Classification for shopping facilities

On the basis of the shopping hierarchy, the shopping facilities were assigned with different weights indicative of the rank of their functions. An example of classification for shopping facilities is shown in Table 6-2 and the spatial interaction between an origin and shopping destination is illustrated in Figure 6-1.

- If this facility is for essential requirements, the weight is assigned with 3.
- If this facility is for necessary requirements, the weight is assigned with 2.
- If this facility is for optional requirements, the weight is assigned with 1.

Table 6-2 Shopping facility classification

Shopping Facility	**Weight**
Bakery, grocery store, Pizza store.	3
Computer store, furniture store, household appliance store.	2
Jewellery store, book store, pet store.	1

(**Note**: For comprehensive shopping facilities like supermarkets, department stores or shopping malls, where both food and non-food items can be found, the weight may be determined as appropriate. In this paper, the weight is still set as 3).

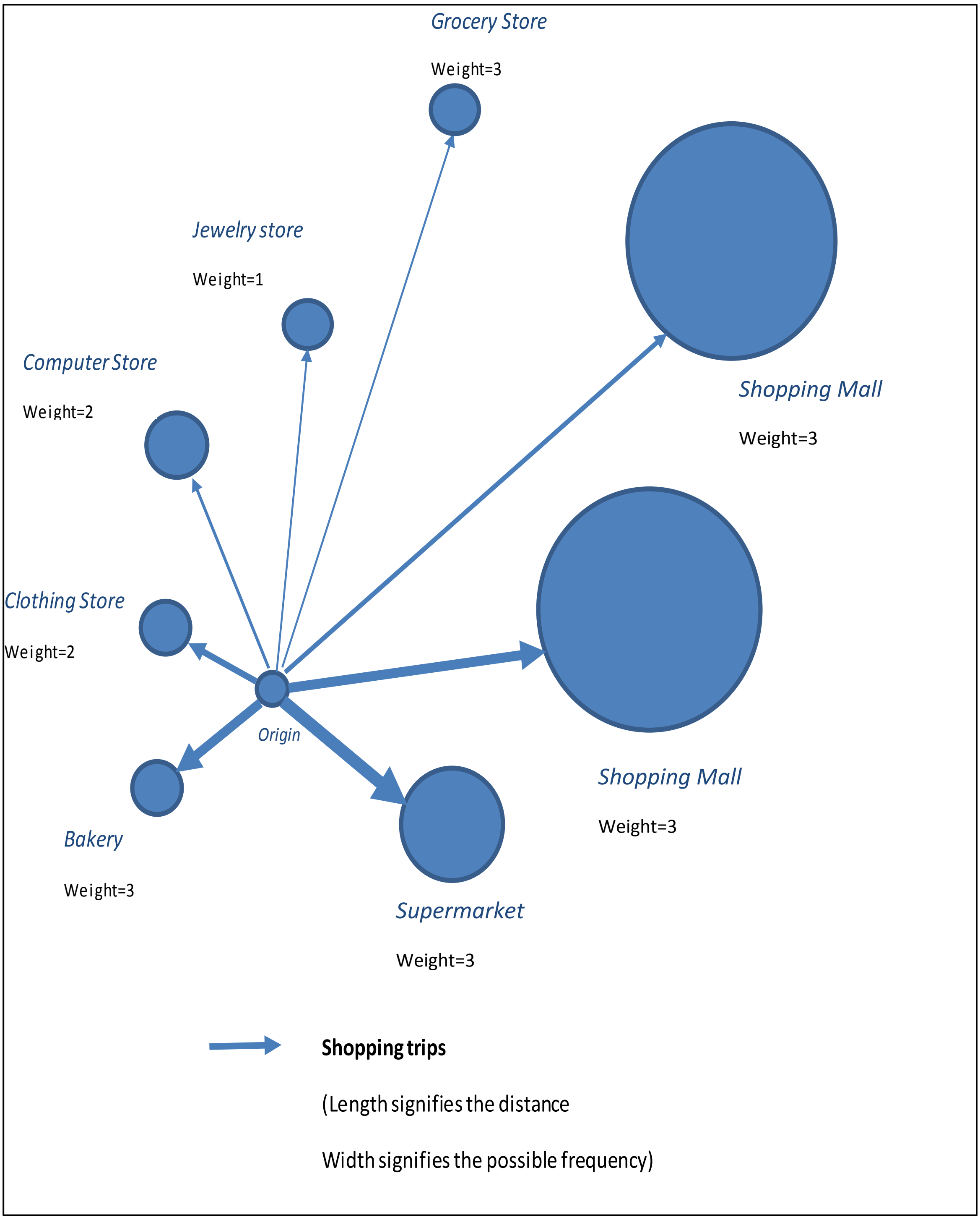


Figure 6-1 The planetary system of shopping activities for an origin

6.1.1.3 Essentiality-weighted shopping model

The Huff model (Huff, 1963) is a spatial interaction model that calculates gravity-based probabilities of consumers at each origin accessing each shopping facility in the study area. As a gravity model, the Huff model is heavily dependent on impedance, such as trip distance or travel time. The definition of the attractiveness of a shopping facility is not generalised, and owing to the lack of available data, only a few tangible factors are used to measure the possibility of consumers patronising each facility as below:

Scale: The size of shopping facility, ***A.***

For grocery store: the value is set at 20-100 m^2.

For supermarket and market: the value is set at 100-5000 m^2.

For department store and shopping mall: the value is greater than 10,000 m^2

Attractor: The frequency to this facility based on essentiality categories, *At*. For example, the attractor of a grocery store or supermarket or department-store is set as 3, the clothing store is set with 2, the antique store is with 1.

Trip momentum: The trip potential from origin *i* to destination *j*. Based on the gravity model in combination with the Huff model, the calculation of a trip potential is calculated from the following equation:

$$W_{ij}=(A \times At)/d_{ij}^{\lambda} \qquad (6\text{-}1)$$

Where d_{ij} is the minimum network distance between origin *i* and destination *j*. λ is the decay coefficient; here it is assigned as 2.

Trip probability: The probability from origin *i* to facility *j*, which is normalised as below:

$$P_{ij} = W_{ij} / \sum W_{ij} \qquad (6\text{-}2)$$

6.1.1.4 Shopping service value

The measurement to evaluate the level of shopping prosperity in an area is usually divided into a number of dimensions including diversity, quantity, and scale. To simplify the calculation, the conception of shopping value is created to represent the average shopping prosperity in a certain area, which is illustrated as below:

$$(SV)_i = \sum_{j=1}^{n} \left(A_j \boldsymbol{At}_j\right) \qquad (6\text{-}3)$$

Where $(SV)_I$ is the overall shopping service value in a study area *i*, A_j is the scale of facility *j*, $\boldsymbol{At}_i$ is the essentiality of facility *j*.

6.1.1.5 Global shopping accessibility

The term, shopping service value, is a quantitative measure to describe the level of shopping service in each cell. Nevertheless, for each origin *i*, the overall shopping activities it can access within a city are distinctive depending on their location, distance to each shopping facility and the attractiveness of each shopping facility. It is obvious that the shopping activities for people living in the city centre are different from those living in suburban areas. Accordingly, the term 'Global shopping accessibility' is defined as the function of shopping frequency, shopping service value in destination *j* and probability of visiting this destination (see Equation (4)).

$$LSV_i = \sum_{j=1}^{n} \left(f_{shopping} \times SV_j \ \times p_{ij}\right) \qquad (6\text{-}4)$$

Where LSV_i is the global shopping accessibility to each shopping cell for origin *i*, $f_{shopping}$ is the annual shopping frequency in origin *i*, which can be obtained from the travel survey. SV_j is the shopping service value in destination *j*, p_{ij} is the probability from origin *i* to destination *j*.

6.1.2 Methodology

6.1.2.1 Spatial analysis for shopping facilities

Mesh grid simplification for study area

To simplify the analysis and reduce the workload, the study area is divided into a fishnet of rectangular cells using GIS tools. Each cell size is set as a 1km×1km square with a centroid (see Fig. 6-2). The centroid is an agent representing the characteristics of origin or destination. For the people living in a cell, it is assumed that they have a similar socioeconomic situation. The difference in age, income, and personal travel preferences are neglected due to the lack of data. All the houses in a cell were abstracted as a point (i.e. the centroid) when running the GIS analysis.

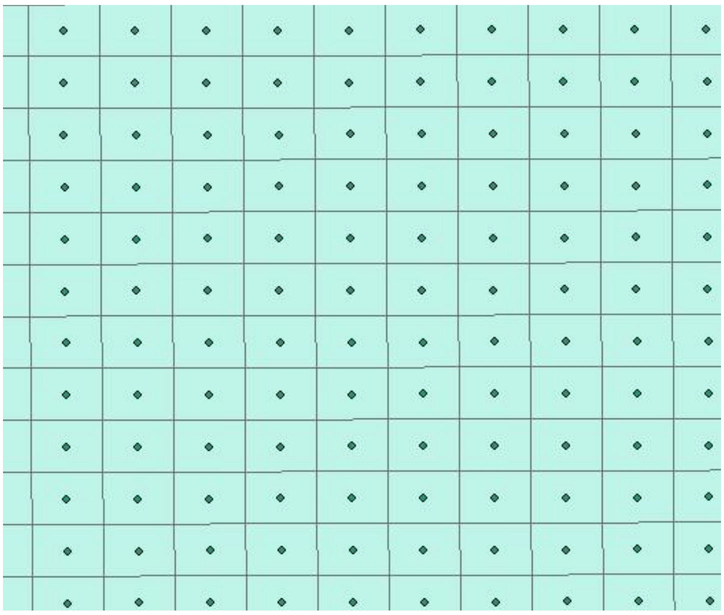


Figure 6-2 An example of 1km×1km urban grid

Classification and quantification of shopping facilities

All the shopping facilities are classified into different categories and assigned with distinctive values according to the rule of essentiality. Then the shopping value in each cell is calculated as the function of number, scale and essentiality of shopping facilities. An example of shopping value distribution in Beijing is presented in Figure 6-3. For a study cell with massive shopping facilities or large-scale shopping malls, the shopping value in this cell is assigned a high value (see the red cells in Figure 6-3). A screenshot of one origin's shopping trips matrix to each shopping destination is illustrated in Figure 6-4. As shown in Figure 6-4, the coefficient 'Value of shopping service' describes the level of shopping facilities in destination j, 'probability to this grid' means the possibility from origin to this destination, and 'distance to this grid' means the minimum travel distance from origin to this destination.

Transport energy calculation on shopping activities

Given the travel survey data and VKT data in a study area, the local area transport energy consumption could be calculated. However, the detailed survey data on shopping activities are difficult to obtain and the individual shopping destinations are extremely random, hence in this paper, it is assumed that for an origin i, all the shopping destinations are accessible with certain possibilities. The trip from origin cell i to each destination cell j is iterated throughout all the study area, and then a weighted shopping trip matrix of origin i is generated as the shopping trip base data to analyse current shopping transport energy use.

Transport patterns assignment

The detailed travel mode share data based on distance bins is required to do adaptive capability analysis. By doing so, the travel patterns in different distance bins are explicit in exploring the possibility of travel mode shift. On the basis of the literature review and travel survey data (Guo, 2010; MOT, 2015), an example of travel mode share matrix of Beijing is listed in Table 6-3.

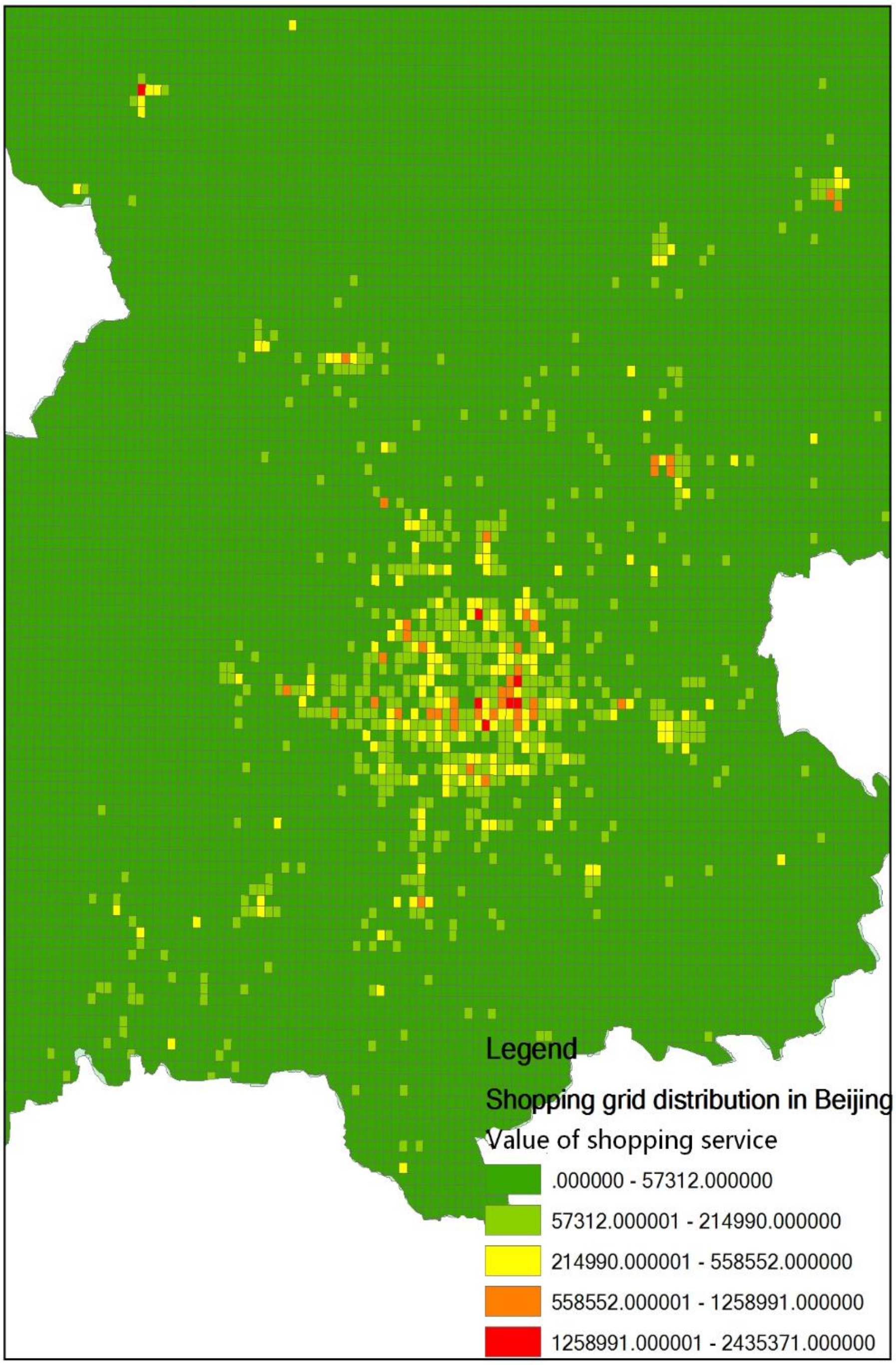
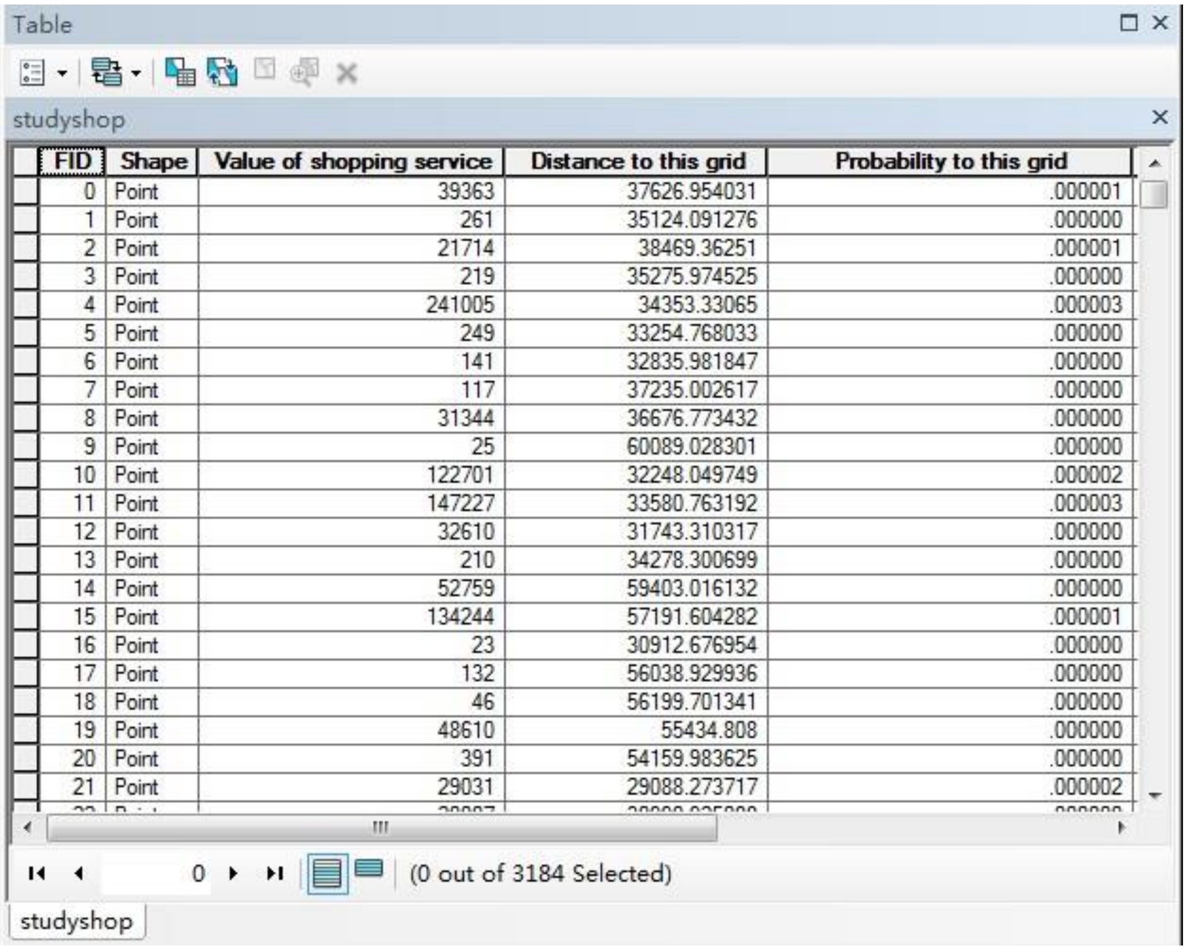


Figure 6-3 An example of shopping value distribution in Beijing



FID	Shape	Value of shopping service	Distance to this grid	Probability to this grid
0	Point	39363	37626.954031	.000001
1	Point	261	35124.091276	.000000
2	Point	21714	38469.36251	.000001
3	Point	219	35275.974525	.000000
4	Point	241005	34353.33065	.000003
5	Point	249	33254.768033	.000000
6	Point	141	32835.981847	.000000
7	Point	117	37235.002617	.000000
8	Point	31344	36676.773432	.000000
9	Point	25	60089.028301	.000000
10	Point	122701	32248.049749	.000002
11	Point	147227	33580.763192	.000003
12	Point	32610	31743.310317	.000000
13	Point	210	34278.300699	.000000
14	Point	52759	59403.016132	.000000
15	Point	134244	57191.604282	.000001
16	Point	23	30912.676954	.000000
17	Point	132	56038.929936	.000000
18	Point	46	56199.701341	.000000
19	Point	48610	55434.808	.000000
20	Point	391	54159.983625	.000000
21	Point	29031	29088.273717	.000002

Figure 6-4 A screenshot of one origin's shopping trip matrix around Beijing

Table 6-3 Distance-based trip mode split in Beijing, China

Trip Mode Split for Shopping (%)	**Distance Bins**(km)					
	*d*1(0-1)	*d*2(1-2)	*d*3(2-3)	*d*4(3-5)	*d*5(5-10)	*d*6(>10)
Walk	89	40	4	0	0	0
Cycle	10	26	30	20	10	0
Bus	0.4	10	30	35	32	35

Car	0.6	10	20	25	35	40
Subway	0	14	16	20	23	25

6.1.2.2 Shopping activities simulation

Using GIS tools and Python programming, an activity-based transportation model was developed to simulate people's shopping activities in a year.

Study area input

1. Demographic data: the population of residents living in a cell (persons/km^2).
2. Origins: the centroid of each cell is seen as the representative of local dwelling distribution.
3. Destination: the centroid of each cell is seen as the representative of local shopping facilities distribution with distinctive shopping values.
4. Transport networks: the travel cost is defined by travel distance. The distances of 3 km and 5 km are defined as comfort and maximum threshold for cycling travel respectively. Congestion and trip chains are neglected.

Constant input

5. Modal energy intensity

Travel mode	**Walk**	**bicycle**	**bus**	**subway**	**car**
Energy intensity(MJ/person×km)	0	0	0.37	0.26	3.64

6. Shopping trip frequency $f_{shopping}$. The average annual shopping frequency at the city level can be derived from travel survey data.
7. Distance-based travel mode share data, T_d.

6.1.2.3 Transport Energy calculation

For an origin *i*, the transport energy consumption for shopping by travel mode is calculated from the following equations:

$$E_i^m = \sum_{j=1}^{n} \left(d_{ij}^m \times em_{mode} \times f_{shopping} \times T_d \times p_{ij} \right) \qquad (6\text{-}5)$$

$$E = \sum_{i=1}^{n} (E_i^m) \text{ /population} \qquad (6\text{-}6)$$

Where E is the average transport energy use per person in origin i, d_{ij}^{m} is the distance from origin i to destination j, em_{mode} is the energy intensity of travel mode, $f_{shopping}$ is the shopping frequency per year, T_d is the distance-based travel mode share.

6.1.3 Case study in Beijing

The above-mentioned approaches were applied to Beijing city to calculate current shopping transport energy characteristics. The urban area of Beijing is around 1368.32 km^2 with a population of 18,590,000, as is shown in the figure. In the aspect of shopping activities, the geographic shopping value for each cell is calculated using Eq.(3) and mapped using GIS (see Fig. 4). It can be seen that the city centre is the important concentration area with extensive shopping activities. Also, there are a number of small shopping clusters in suburban areas.

For each cell, the travel patterns and shopping values in different distance bins were calculated based on trip mode split for shopping. A cell close to the city centre of Beijing (cell A in Figure 7) and another one faraway (cell B in Figure 7) were selected as an example to show how the distance and shopping facility distribution affect trip frequency and shopping activities. Cell A is closer to the high-value shopping districts resulting in higher frequencies and better shopping service available within 5 km. For people living in cell B, the motorised travel requirement is generated if they want to access more shopping facilities because of the lower level shopping services within a short distance. By analysing the travel patterns in each cell, the adaptive capacity and related shopping value at micro level could be derived as a close-up observation for analysis.

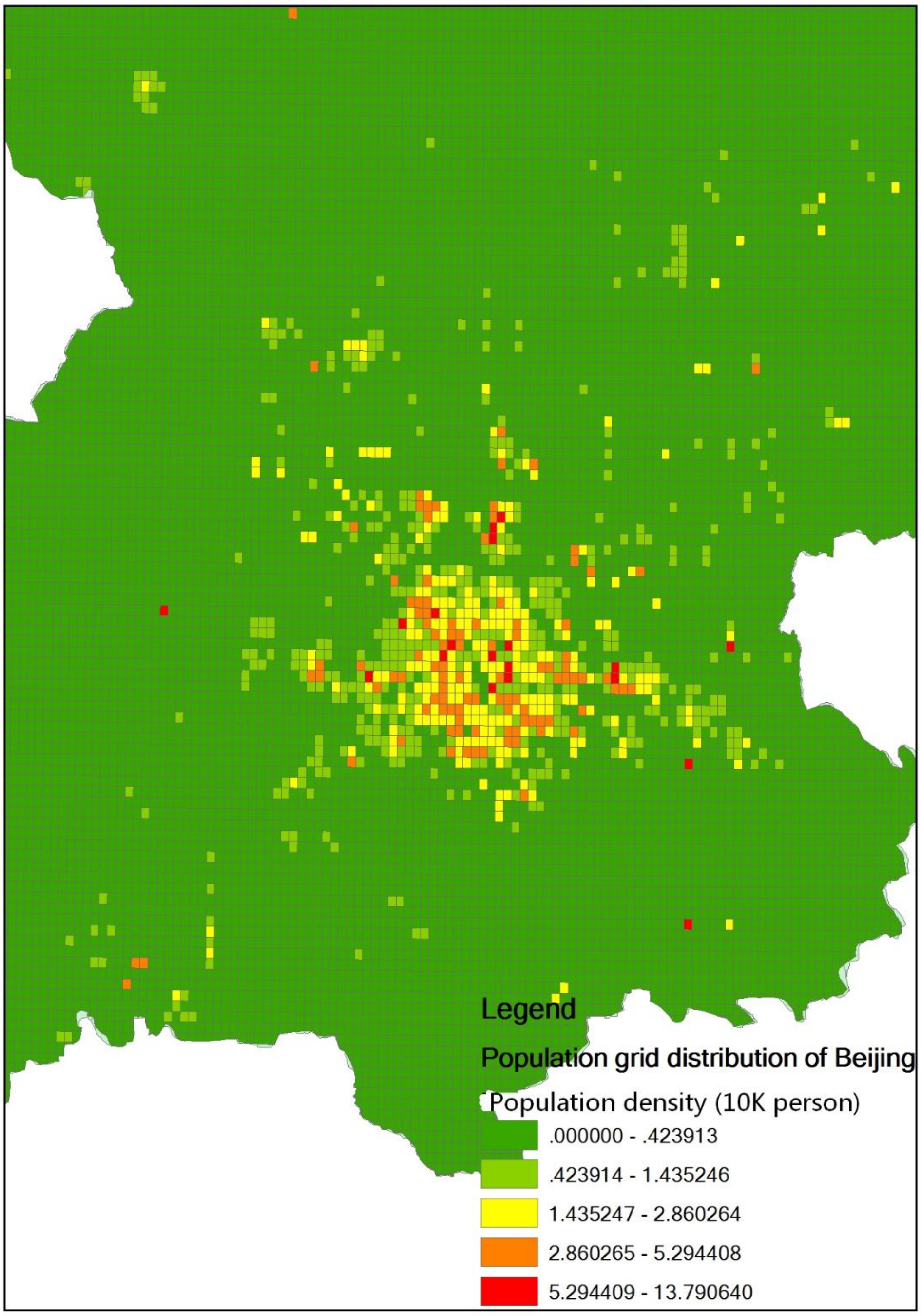


Figure 6-5 Population density distribution in Beijing

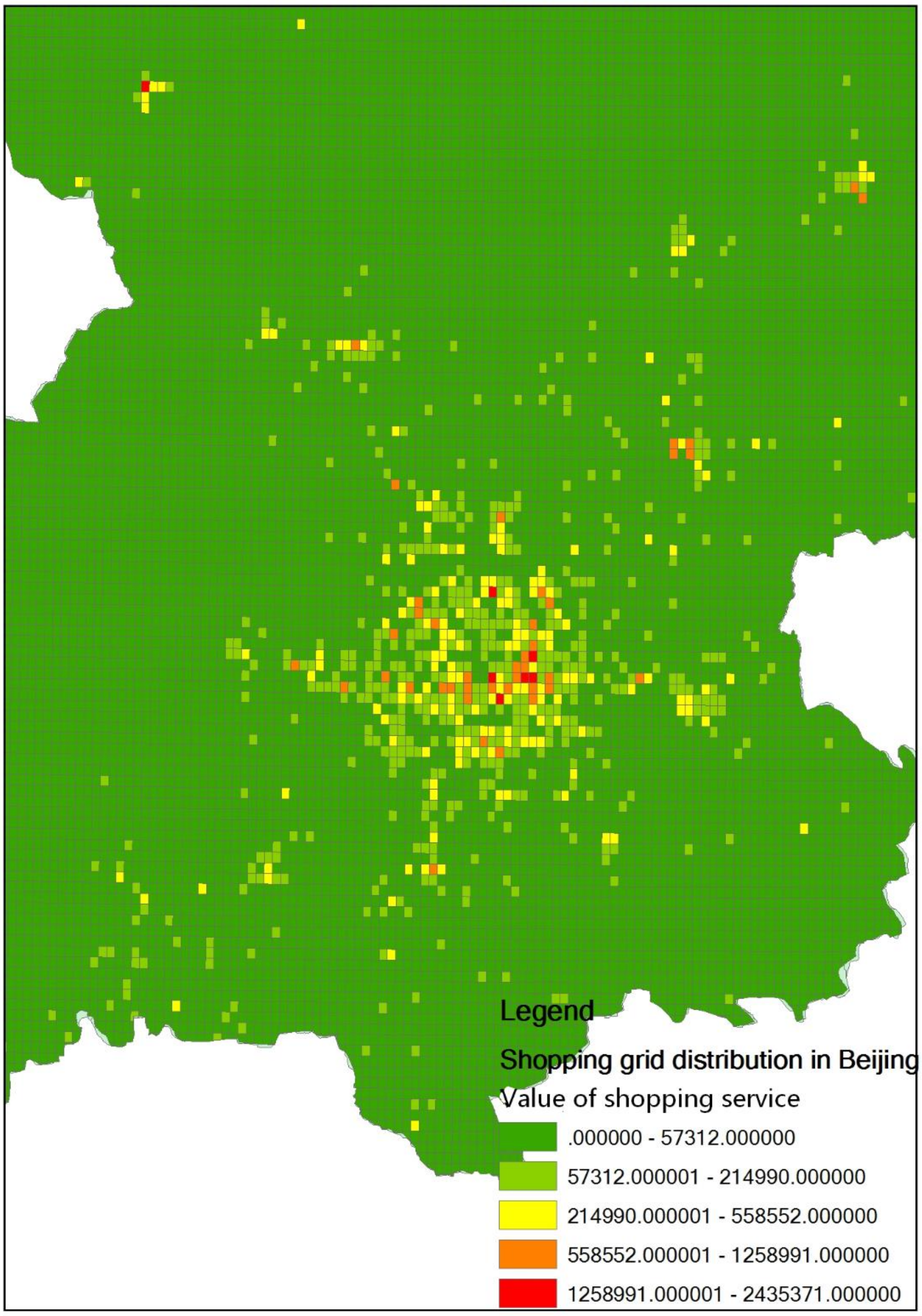


Figure 6-6 Shopping value distribution in Beijing

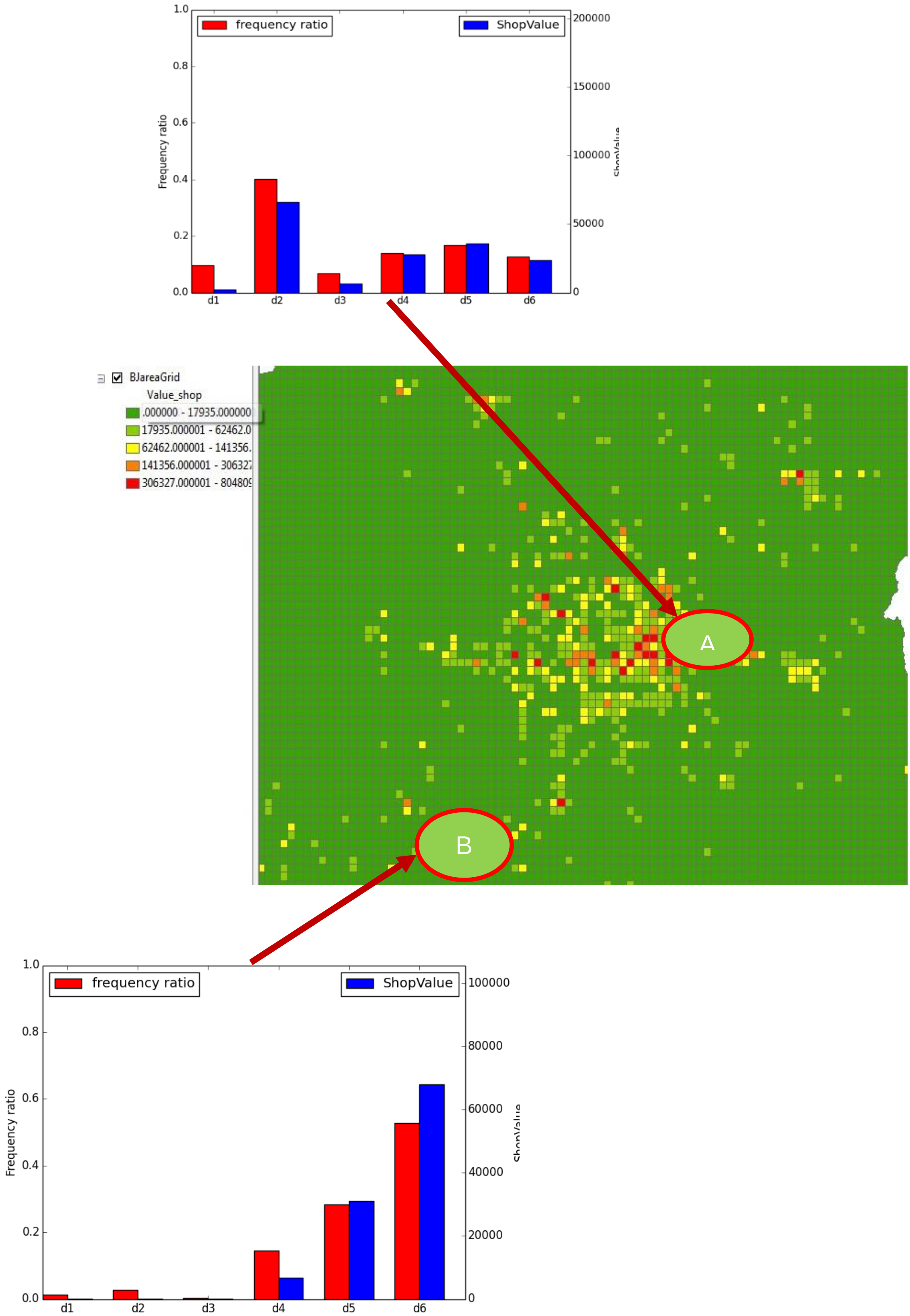


Figure 6-7 Example of travel patterns in each cell

The calculation of current transport energy consumption in each cell was iterated throughout Beijing city area using Eq. (5) and (6) and mapped by applying the interpolation method in GIS, which is shown in Fig 6-8. Not surprisingly, the city centre and surrounding areas have the lowest transport consumption because of the higher density of population and higher level of shopping services. On the outskirts of Beijing city, there exist several regions with lower transport energy use due to the long distance to the city centre. Combined with the shopping value map in Beijing, the level of shopping services in these regions is fairly good reducing the travel demand for the city centre. It is generally argued that the carbon emission is negatively related to the population density, which is testified by the transport energy consumption vs. population density analysis in Fig. 6-9. All the cells in each city were transformed into a scatter chart with a division line and a trend curve highlighted in these two figures. It can be seen that transport energy consumption has a somewhat descending trend as the population density increases with the majority of Beijing's shoppers consuming no more than 4000MJ/year. Table 6-4 is a comparative analysis of transport energy use, Vehicle Kilometres Travelled (VKT) and average trip distance for shopping activities in Beijing.

Table 6-4 Shopping transport energy performance in Beijing

City	**Average transport energy use for shopping(MJ/person)**	**Average weighted VKT for shopping(km/year)**	**Average trip distance for shopping(km/day)**
Beijing	1286.78	301	11.08

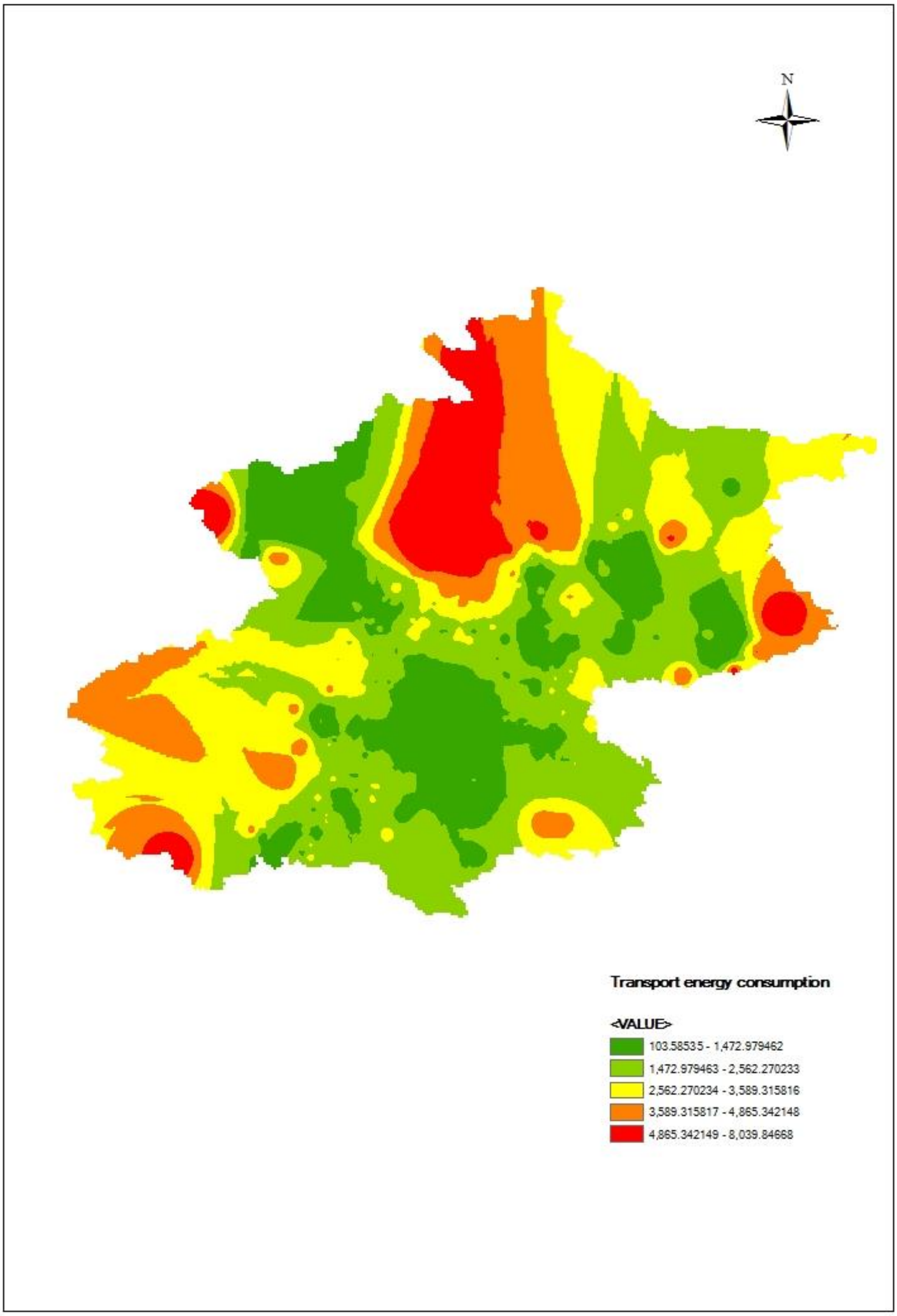


Figure 6-8 Current Shopping Transport energy consumption distribution map of Beijing

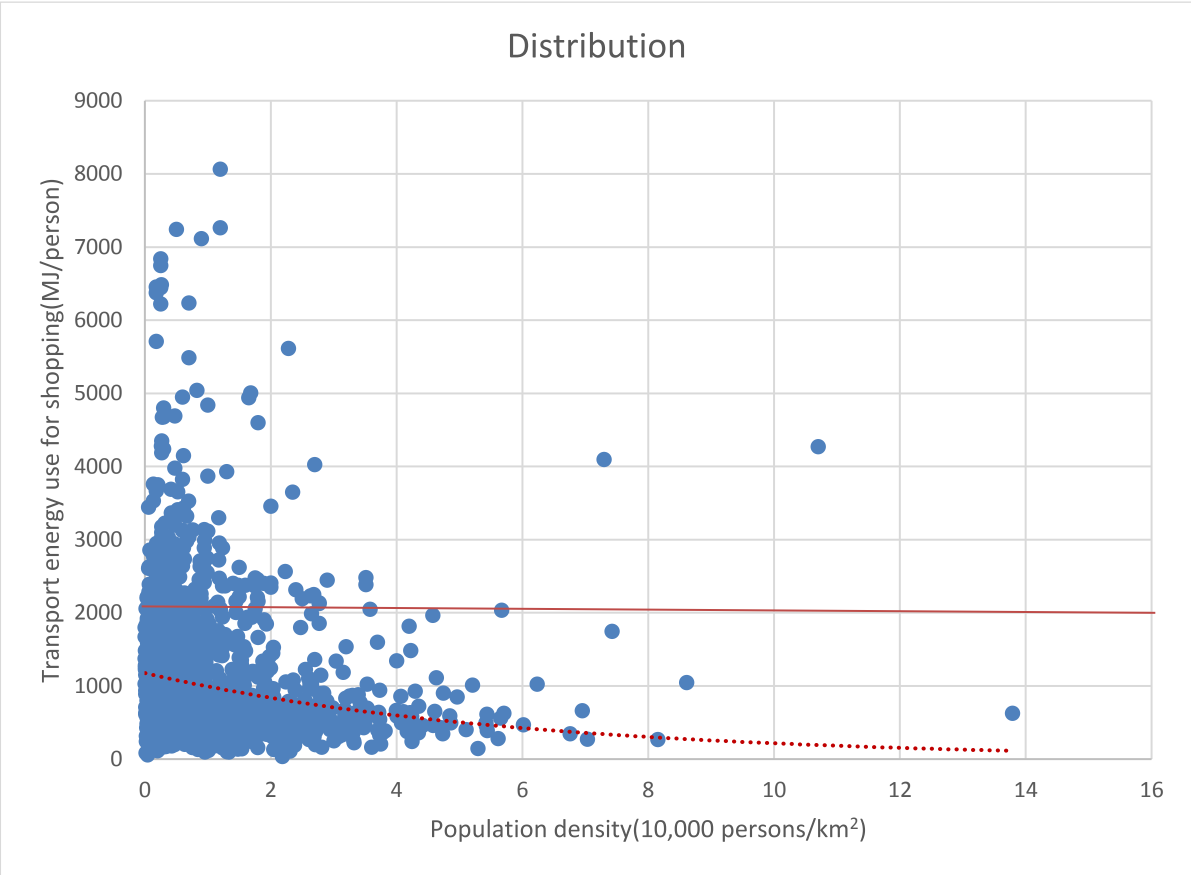


Figure 6-9 Correlation between transport energy use and population density in Beijing

6.2 Modelling commuting distance distribution

Figure 6-10 is the employment-population distribution map showing the current jobs-housing imbalance in Beijing: the concentration of employment in the city centre and the sprawl of residences in suburban areas. There are even several single-function residential areas in the north where the job opportunities are limited but the residents are abundant. Meng (2009) found that the imbalance of jobs-housing in Beijing has become an obvious trend entailing a longer commute distance. The average commute time is around 38 minutes; more than 43.7% of commuters spend more than 40 minutes commuting. According to BJTRC (2015), the bike mode share for work trips in Beijing has declined from 62.7% in 1986 to 12.6% in 2014 (see Figure 5-8), whereas the car mode share had gradually increased peaking at 34.2% in 2010 and then slightly dropping down owing to the implementation of car use restriction policies by the municipal government of Beijing since 2009.

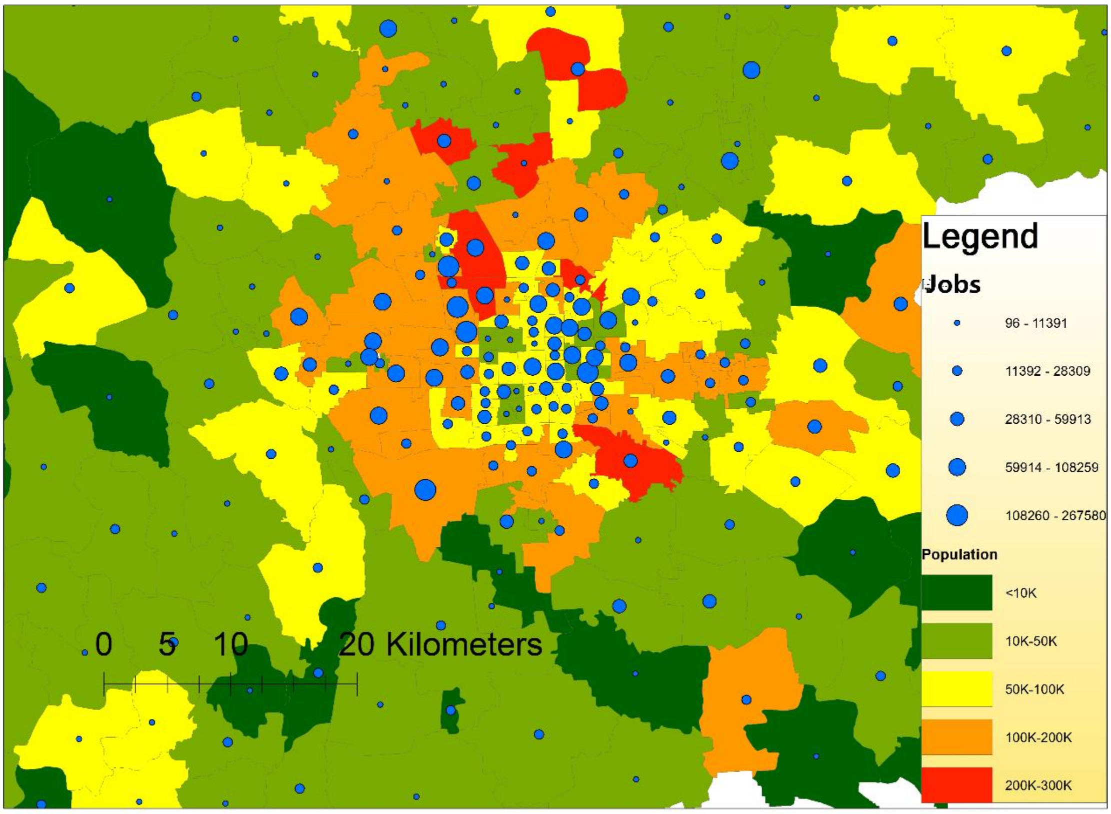


Figure 6-10 Employment-population distribution in Beijing

In order to learn about the current commute pattern of Beijing, a large amount of travel survey data including commuter's home address, workplace, age, car ownership, and income are required for further analysis. However, due to the difficulty in obtaining such detailed commuter data, on the basis of 5000 inhabitants' samples with their home addresses and workplaces, a distance-resolved commute model was developed to understand the commuting distance distribution in Beijing at the region level.

A number of pieces of research have been carried out to unravel the nature of human trajectories and locations by virtue of the emergence of big-data and the improvement in technology. A noticeable study by Gonzalez et al. (2008) argues that the distribution of human displacements is well approximated by a power-law as follows:

$$P(\Delta r) = (\Delta r + \Delta r_0)^{-\beta} \exp(-\Delta r/\kappa) \quad (6\text{-}7)$$

with exponent β=1.75±0.15 and $\Delta r_0 = 1.5$ km. The research findings indicate that the travel patterns of people could be quantified as a spatial probability distribution, the highest probability occurring in a few frequently visited locations. Following this way, the sample data in Beijing with residents' home addresses and workplaces were studied in order to characterise the commuting distance distribution in Beijing.

6.2.1 Data source and explanation

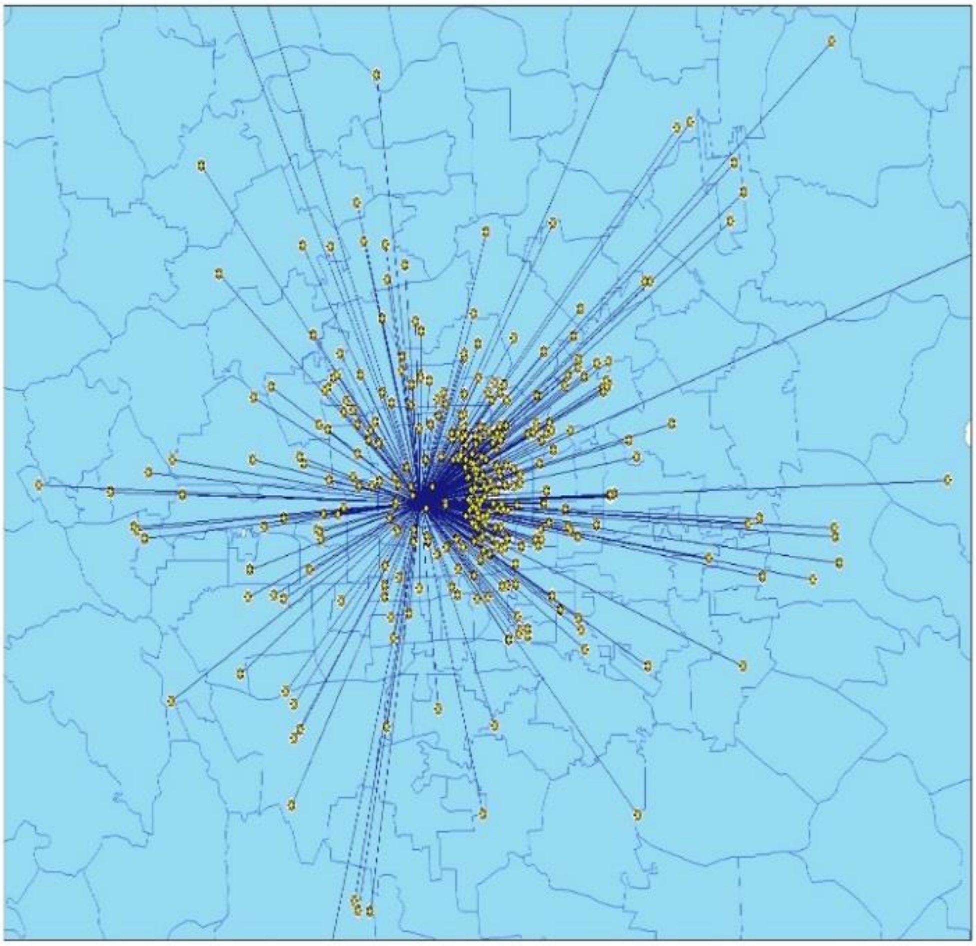
Owing to the limitation of data availability, it is difficult to obtain the current work trip distance matrix in Beijing. Based on a number of publications about the personal information of home buyers derived from websites of local governments, 5000 samples were collected with their current workplaces and home addresses included. After a geocoding process, the minimum network distances from home to workplace were calculated with the assistance of a GIS system. A fragment of this sample data is exemplified in Table 6-5 with their addresses and workplaces being concealed for confidentiality. The sample data were divided into two groups: one is utilised as training data for model development and the other one is test data for validation purpose.

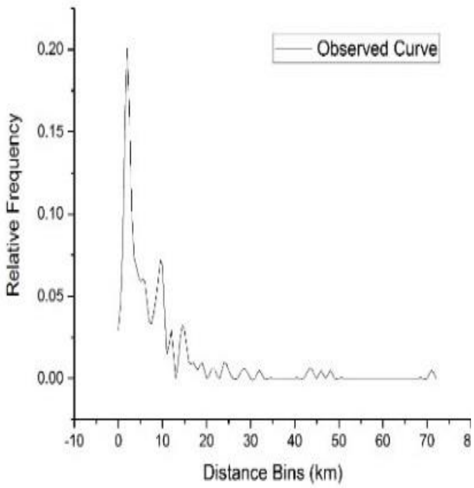
Table 6-5 A screenshot of resident sample data in Beijing

Name of sub-district	Home address	Workplace	Minimum Network Distance (km)
Chengguan sub-district	Tongzhou * ***	Beijing * ***	16.04
Chengguan sub-district	Tongzhou * ***	Beijing * ***	24.32
Chengguan sub-district	Tongzhou ***	Tongzhou* ***	27.58
Chengguan sub-district	Tongzhou* ***	Tongzhou * ***	111.64
Chengguan sub-district	……	……	……

6.2.2 Data mining

Distance grouping. First 2500 samples in different sub-districts were randomly selected as the training data, the distance and number of commuters to destination sub-districts from an origin sub-district can be obtained from the sample training data. In order to explore the underlying laws governing distance distribution, all the OD distances were grouped into consecutive distance bins based on intervals of 1000 m, and then the number of commuters in each distance bin were summed up. Thus, the quantity of commuting trips in different distance bins was obtained, then the relative probability of commuter's distance-based distribution and the cumulative probability can be calculated using Origin Software. The distribution of PDF and CDF of a region in the city centre and a region in the southwest suburban area of Beijing city are exemplified in Figures 6-11 and 6-12 respectively.





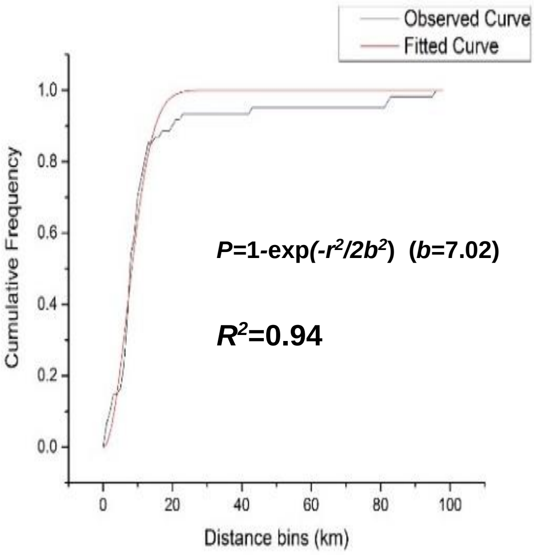


Figure 6-11 The distribution of workplaces and commute flows for residents living around the city centre of Beijing

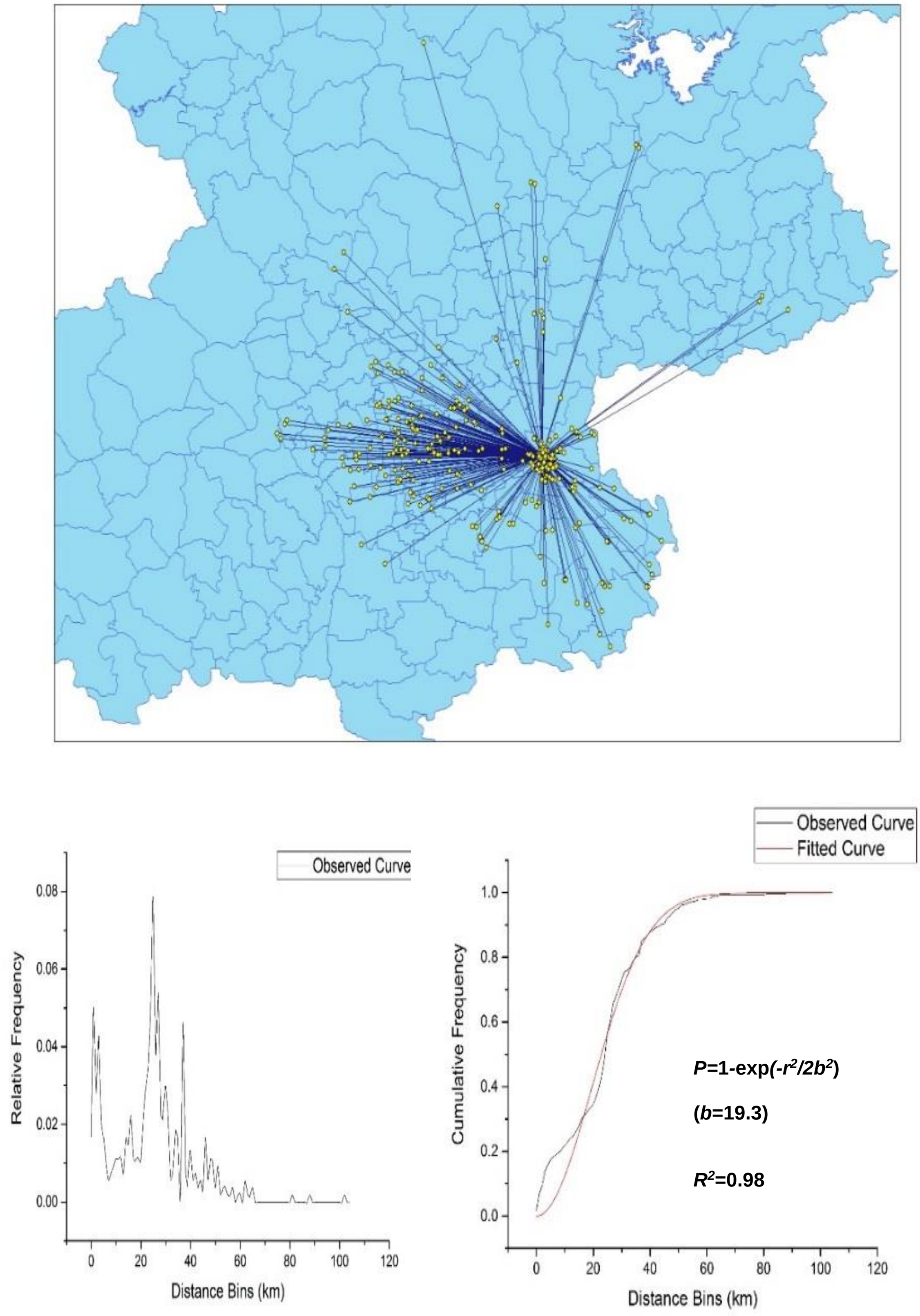


Figure 6-12 The distribution of workplaces and commute flows for residents living around a suburban area of Beijing

Curve fitting. As for the possibility density distribution, it looks like a multiple peak distribution, which is difficult to fit with an explicit mathematical function. The cumulative density curve, by contrast, exhibits a goodness of regularity and can be fitted with a statistical function (see Figures 3 and 4). After a number of fitting trials for different regions, it was revealed that the exponential function family (e.g. Gamma, Rayleigh and simple exponential) best fit the cumulative possibility distribution (R^2>85%). On the other hand, the Gamma function takes a complicated form with two parameters to be determined, the Rayleigh CDF function was employed in this paper to represent the commuting distance distribution owing to its simple form with only one parameter to be determined (see equation (6-8)).

$$F(d) = 1 - \exp(-d^2/2b^2) \quad \text{(6-8)}$$

Parameter analysis. First, 20 census tracts were randomly selected as the training data (see Table 6-6), and, after the curve fitting process, the parameter for each study region was then obtained with regional attributes such as residents' population, employment opportunities, and the number of workplaces being considered.

Table 6-6 Training data profile of each sub-district in Beijing

Name of sub-district	Parameter value *b*	Average distance to employment catchment	Population	Employment opportunities	Average distance to all employment facilities
Hepingli	4.97	10.68	112058	105057	22.10
Datun	6.78	13.81	141433	118696	23.95
Dahongmen	6.52	15.87	193382	50700	26.33
Dongzhimen	3.77	10.87	46018	79794	21.78
Fangzhuang	7.14	13.84	83454	46700	24.42
Beixinqiao	2.99	10.43	82273	73462	21.53

Zuojiazhuang	7.15	11.53	80249	81352	22.62
Chaowai	5.64	10.96	39999	101976	21.97
Taiyanggong	5.73	12.38	70367	31805	22.83
Donghuamen	3.34	10.41	61366	151248	21.79
Chengguanzhen	15.36	27.97	73423	20557	33.97
Xiangheyuan	5.93	11.54	51880	21445	22.32
Jiangtaixiang	7.60	14.81	71341	27786	24.69
Pingguoyuan	9.54	22.81	101775	85683	31.34
Maizidian	5.96	13.05	31741	76147	23.12
Xincun	10.46	19.04	159357	145246	30.46
Dongba	10.13	19.59	88541	15786	27.34
GuanganmenNei	6.59	11.43	73692	52513	23.16
Taoranting	5.82	12.15	43455	8991	23.16

It has been established that the commuting activity is a multi-dimensional complex system influenced by a wide range of factors, such as land use, demography, economic situation, and personal preference (Van Acker & Witlox, 2011; Rouwendal & van der Vlist, 2005). Besides this, according to Salze et al. (2011), the distance to major urban poles plays a significant role in affecting commuters' spatial accessibility to facilities on a regional scale. Subsequently, a couple of easy-to-capture variables, such as the average distance to major employment facilities in a city, local population and employment opportunities, as well as the number of workplaces in each origin zone, were adopted as the explanatory variables to analyse their relationship with the value of the parameter. Further studies by SPSS statistics revealed that only the log-transformed average distance to major employment catchments have a high correlation to the value of the parameter to be determined (see Figure 6-13). Also, the value of the parameter in each study region can be approximately expressed as a linear function (Figure 6-14):

$$b = \alpha \ln(\overline{d_\iota}) + \beta \quad \text{(For Beijing, α=9.348, β=-17.604)} \qquad (6\text{-}9)$$

where $\overline{d_\iota}$ is the arithmetic mean distance to major employment catchments for study region *l*; α, β are specific parameters for a study city. The identification of the major job markets (i.e. employment catchment) can either be obtained from official data, or be generated by the combination of workplace location with associated job opportunities (see Figure 6-15) with the assistance of the Kenel density tool of ArcGIS system.

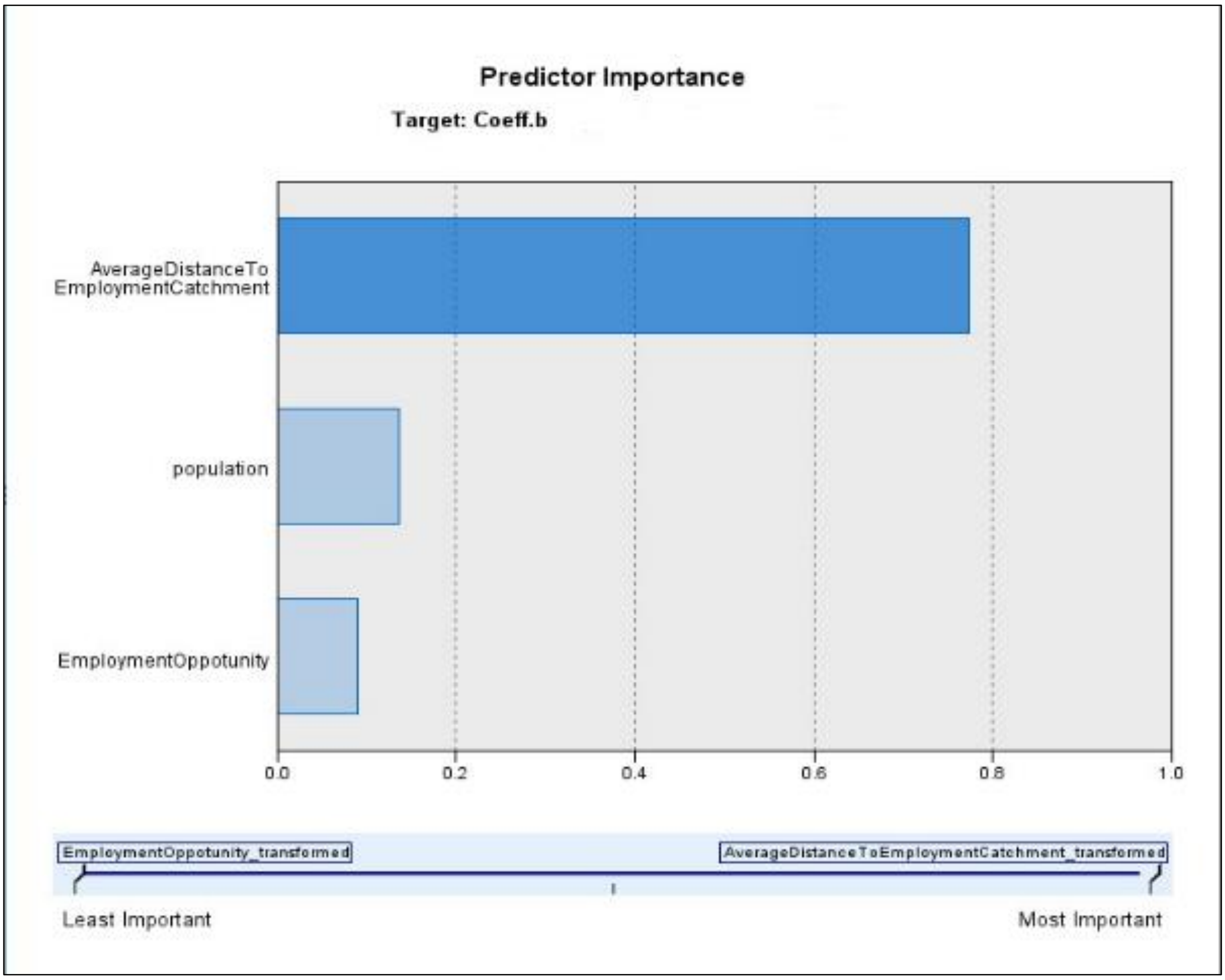


Figure 6-13 Correlation analysis between explanatory variables and the parameter

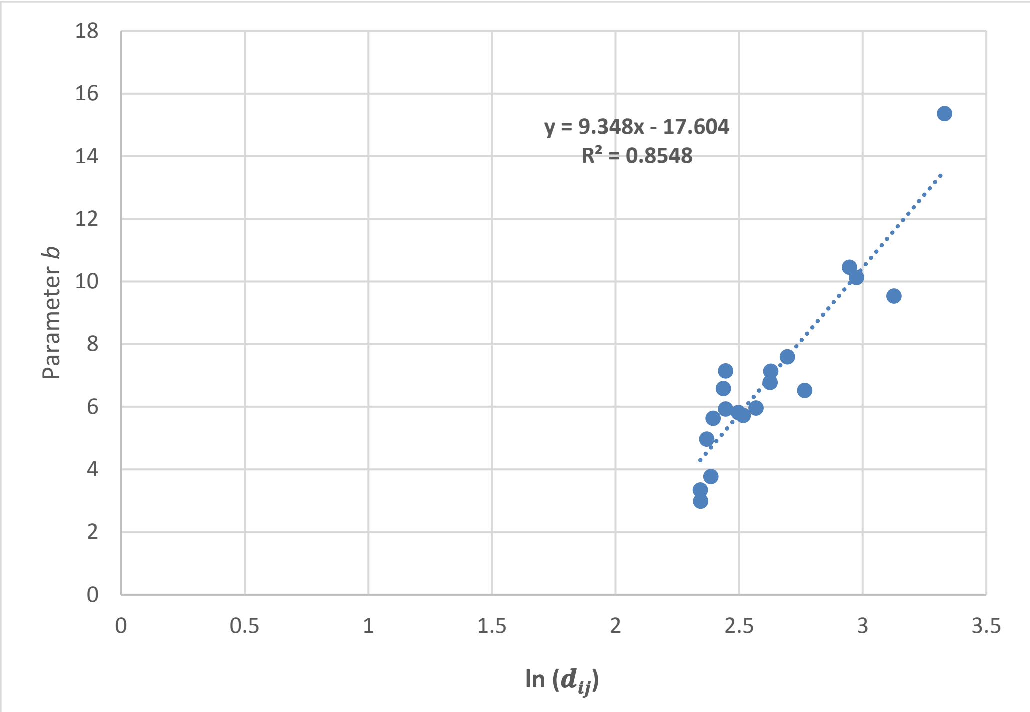


Figure 6-14 Parameter value of sample as a function of the average distance to the employment catchment

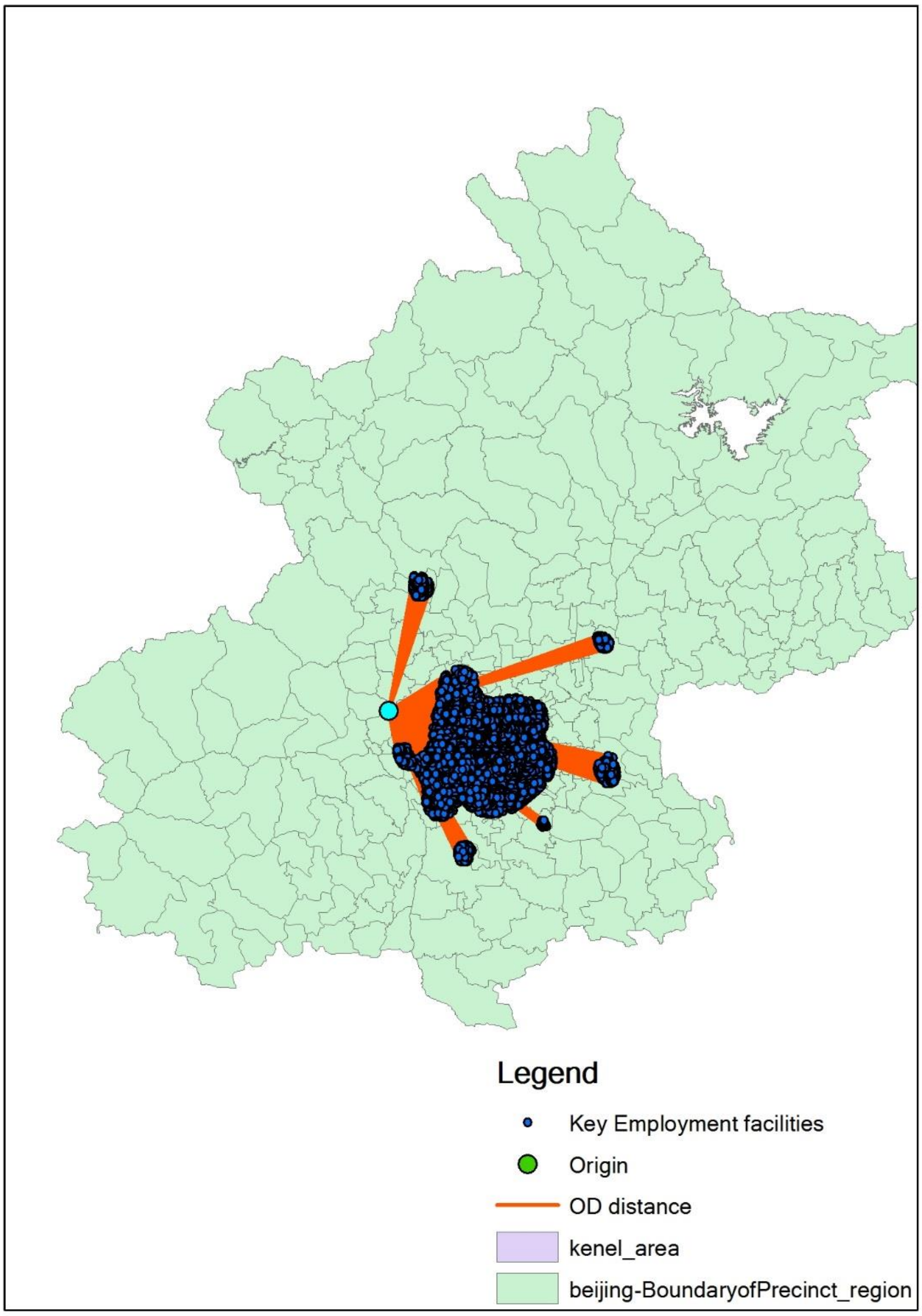


Figure 6-15 Example of calculating average commuting distance for an origin

6.2.3 Validation

The remaining 2500 samples in different sub-districts were randomly selected as the test data to validate the accuracy of the developed model. The average distances to employment catchments for these sub-districts have been calculated with the ArcGIS system and then substituted into equation (5) to obtain the simulated value of the parameter. Then the real cumulative possibility distribution curve of commuting distance for each census tract was fitted with a Rayleigh function respectively; afterwards the observed distribution parameters were acquired through the fitting process. The comparison between observed parameters and predicted parameters is tabulated below (Table 6-7). It can be seen that the majority of results are within acceptable error range (<20%).

Table 6-7 Comparison between observed results and simulated results

Name of sub-district	**Observed parameter**	**average distance to employment catchments**	**Simulated parameter**	**Relative error (%)**
Liulitun	6.06	13.75	6.89	0.13
Maizidian	6.17	13.43	6.68	0.08
Laiguangying	10.85	16.79	8.76	-0.19
Walixiang	7.69	15.54	8.04	0.04
Lucheng	14.79	26.39	12.99	-0.12
Changqiao	4.25	10.32	4.22	-0.01
West Changanjie	4.57	10.50	4.38	-0.04
Jinsong	8.71	13.82	6.94	-0.20
Hepingjie	5.51	11.86	5.51	0.001
Xiaoguan	5.41	12.80	6.23	0.15
Jianwai	5.36	11.96	5.59	0.04
Fengshengjie	5.66	10.51	4.39	-0.22
Erlonglu	6.51	10.72	4.57	-0.29

Yuetan	6.27	11.28	5.04	-0.19
Fengsheng	5.75	10.57	4.44	-0.22
Dewai	5.59	10.99	4.80	-0.14
Qinghe	9.48	17.74	9.28	-0.02
Zhongguancun	6.32	13.78	6.92	0.09
Wanshoulu	7.77	15.06	7.75	-0.01
Ganjiakou	5.87	12.26	5.82	-0.01

In summary, this model can be mathematically expressed using the following equations:

$$\begin{cases} P_i = 1-\exp\left(-d^2/2\lambda_i^2\right) \\ \lambda_i = \alpha \ln\left(\bar{d}_{ij}\right) + \beta \\ \overline{d_{ij}} = \frac{1}{m \times n}\sum_{j=0}^{m} d_{ij} \end{cases} \quad \textbf{(6-10)}$$

where P_i is the proportion of commuters from origin *i* within a specified distance *d*, the value of λ is determined by the average distance to key employment places $\bar{d}$, which is calculated by d_{ij}. Also, d_{ij} is the distance from origin *i* to a workplace *j* in the employment catchment. The employment catchment can either be obtained from official data (if any) or be calculated based on the integration of employment opportunities and distribution. α, β are unique urban characteristic values assuming they would remain stable for a long time. Therefore, given a small amount of travel survey data, once the required parameter is deduced, the trip distance distribution for any region in question could be calculated as the result.

Table 6-8 Distance-based travel mode split in Beijing

Travel distance	Travel mode split (%)					
	walking	bike	bus	subway	car	others
d_1(0-2 km)	56.4	29.08	3.05	0.02	7.6	3.54
d_2(2-5km)	4.5	30.04	30.51	0.81	30.17	2.33
d_3(5-10km)	0.41	14.03	40.37	8.51	42.14	0.81
d_4(>10km)	0	5.1	30.37	14.32	52.2	14.37

(**Source**: Huang Shu-sen et al. (2008))

Based on the distance-based travel mode split in Beijing (Table 6-8), the current commute characteristics by private car in Beijing can be produced from equation (6-11).

$$C_j^{d_i} = P_j \times (1 - exp(-d_i^2/(2\lambda_j^2))) \times T_C^{d_i} \quad (i\text{=1,2,3,4}) \qquad (6\text{-}11)$$

where $C_j^{d_i}$ is the number of car trips in a specified distance bin d_i from an origin region *j*, P_j is the employed population of origin *j*, and $T_C^{d_i}$ is the car mode share in the d_i from origin *j*. It is assumed in this paper the distance-based car mode share in each traffic zone follows the same travel mode split as presented in Table 1.

6.3 Conclusion

The previously mentioned models present two quantitative methods to characterise shopping activities and commute activities respectively, whereby the proportion of travellers to a certain destination zone can be estimated with less data requirements. The developed shopping model is a modified Huff model to quantify spatial interaction between consumers and merchants, in which the essentiality-based hierarchy of shopping facilities are incorporated to indicate the importance of different kinds of commodity to human wellbeing. The developed commute model is a statistical simulation for trip distance distribution of commute activities, in which the population, commuting distance and the employment centres are assumed to be the primary determinants. These activity-modelling studies have a positive significance for urban planning, transportation management and travel demand prediction. For instance, when it comes to urban resilience or an active transport system, a pressing problem is to learn about how many trips would be generated in different distance bins during urban development. In the absence of data availability, these approaches provide convenient tools for urban transport planners to assess how trip distances vary with the layout of shopping facilities, employment opportunities and population distribution.

7. Future Scenarios

In the face of environmental deterioration and peak oil, western countries have begun to deliberate over the study on the new urbanism and compact city form to decrease high reliance on fossil fuel; China, however, resembles early western urban sprawl pattern with more focus on automobile-oriented development during its urbanisation. Almost all the development projects in China are based on the premise that the future energy supply will be adequate and the car-driving lifestyle will be prevalent in the future. This chapter presents several major development trends in China to examine their potential risks for future sustainable development.

7.1 Urban sprawl trend

According to Mi, Schmid and Feiner (2001), the current development dynamics in China can be characterised by:

- Population growth
- Strong urbanisation tendency
- Dynamic economic growth
- Industrialisation and modernisation
- Rapid motorisation

This kind of development pattern would lead to a number of negative consequences, including the massive movement of population from rural areas to newly developed urban areas with accompanying unemployment problems as well as the urban land extension with scattered low-density development. Although the reinforcement of the policies regarding the balance of rural-urban areas is strong, economic forces become increasingly dominant during the process of urbanisation, giving impetus particularly to the growth of the large cities. In addition, Cao et al. (2014) pointed out that although more people live in cities, it is harder for them to enjoy living there. The result is a crowded, noisy, and unhappy place to live, which is obviously not the aim of urbanisation. Statistical data suggests that the larger the city, the greater the mean income and the greater the social welfare resources, such as education, medicine, and insurance that are provided to its registered residents (NBS, 2000–2012). But this has widened the income gap between urban and rural residents by nearly 45 times, from 286 RMB per year in 1978 to 12.8×10^3 RMB per year in 2011, during which time the ratio of urban to rural income increased from 2.5:1 to 3.4:1 (NBS, 2012).

Besides the population urbanisation growth, the urban land expansion is more intensive with uneven geographical distribution. Dongfeng et al. (2013) found that between 1993 and 2009 the total population living in prefectural areas of cities increased by 75%, from 126.57 million to 219.82 million. On the other hand, built-up urban areas more than doubled over the same period, thus the built area of Beijing has expanded significantly from 454 km^2 in 1993 to 1401 km^2 in 2015, resulting in the growth of average travel distances over recent decades. For example, Wen et al. (2012) found that nearly 75% of commuters in Beijing travel more than 5 km to work. Furthermore, it seems that the sprawling tendency will continue in the future as shown in the master plan of Beijing (2004-2020) (BJGHW, 2006, see Figure 7-1). From Figure 7-1, it can be inferred that the average urban radius would increase from 37 km in 2015 to 61 km in the future, supposedly 65% growth in average travel distance. With the decline of conventional work unit form and the dispersal of land use, the proportion of motorised trips has gradually increased causing negative impacts like high energy consumption, traffic congestion and air pollution. Apart from that, the independent fiscal responsibility for local governments drive them to promote local industrialisation in the form of scattered townships or village enterprises without considering regional or global cooperation (Zhao, 2010).

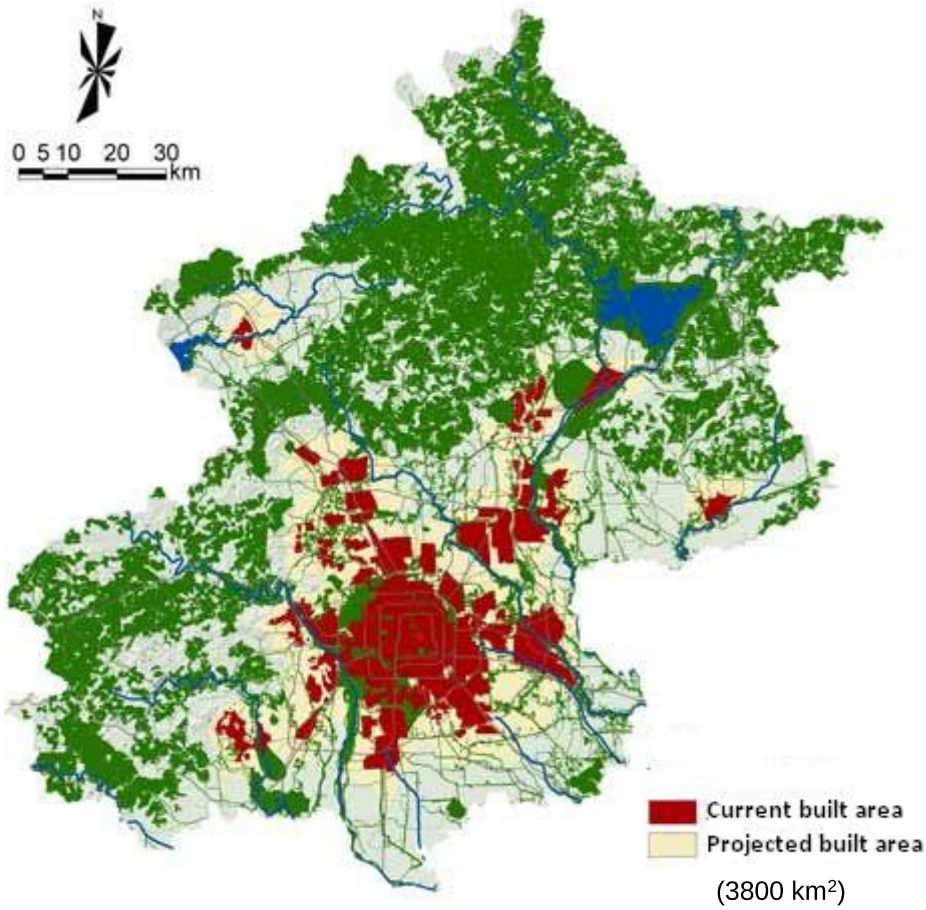


Figure 7-1 Urban growth trend of Beijing (adapted from Kongjian et al. (2010))

7.2 Fuel economy

Fuel economy improvement receives extensive attention around the globe. Some developed countries have enforced high standard fuel economy regulations and a variety of incentives and policies have been implemented to encourage the use of energy efficient vehicles. China also has attached importance to energy efficiency in transport sectors. However, currently there is no mandatory national standards for vehicle fuel economy implemented in China, although some energy conservation measures have been put into effect. At present it is estimated that the fuel economy of new Chinese vehicles is 10%-25% lower than that in some developed countries (He et al., 2005).

Basically the energy consumption of one vehicle is a function of the type of engine, travel distance, driving speed, load capacity, the energy intensity of engine and the distance travelled being the most influential factors. For the sake of simplicity, the total transport energy consumption can be expressed as:

$$E=Ned \qquad (7\text{-}1)$$

where e is the energy intensity of engine, d is the average distance travelled per vehicle, and N is the number of running vehicles. Assuming that the energy intensity of future Chinese vehicles could be reduced by 30%; however, the travel distance in the future might be increased by 65% according to the ongoing urban growth trend described in Section 7.1. Consequently, the average energy consumption per vehicle may be increased by 45% (65%*(1-30%)), indicating that the sprawling urban development might far offset the improvement in fuel economy. Moreover, with the rapid increase of car ownership, it is foreseeable that the total transport energy consumption in the future would continue to grow at a faster pace.

7.3 Electric cars

With regard to transport energy conservation, much attention in China's S&T has been paid to decarbonisation in terms of technological transformation, such as electric cars, renewable energy resources, vehicle emissions controls and so forth. It is widely believed by many government agencies that the Plug-in Electric Vehicle would be an alternative to fossil fuel cars in the future, being cordially supported with large amount of incentives and subsidies. However, the large-scale implementation of electric cars is still far away from reality on the grounds of the following:

- Technological bottleneck. The lithium-ion battery is the key to electrical car development; however, the prospect for breakthrough in this field is uncertain (Liu et al., 2015). Also, the lack of extensive charging infrastructure is the most commonly cited barrier to PEV adoption everywhere in the world (Sathaye & Kelley, 2013).
- Environment and energy risks. The use of PEVs still requires additional electricity and the operation of a power grid system, leading to indirect emissions with the increase in generation capacity, transmission and distribution (Parks, Denholm, & Markel, 2007). Taking into account the predominance of coal power in the Chinese electricity market (nearly 80%), it does not necessarily follow that the PEV would mitigate environmental pollution.
- Commercialisation predicament. The lifecycle cost for electric vehicles, even with scenarios of mass production may be too high (Cuenca, Vyas, & Gaines, 1999). Although the central government of China encourages PEV sales, only 1428 residents in Beijing applied for PEV license plates in 2014, showing a relatively low willingness to purchase PEVs (Bloomberg, 2014). Also, the regional protectionism in China obstructs the development of the PEV market and undermines national PEV policy (Wan, Sperling, & Wang, 2015).

- Transport congestion problems still exist even though the substitution of electric car is realised.

Apart from that, all of the alternative vehicle platforms and fuels still would require a massive network of roads and all of the attendant costs associated with private vehicle mobility (European Expert Group on Future Transport Fuels, 2011). Any future scenario that has continued growth of travel demand and does not involve reduction of demand for fossil transport fuels would still face serious reliability and sustainability risks (Krumdieck, 2011).

7.4 Conclusion

China is now undergoing large-scale road transportation infrastructure building and a booming automobile industry development. Meanwhile, China's government regards the urbanisation of rural areas as a significant symbol to evaluate the level of development, which is characterised by the tendency to convert rural land into housing communities or economic development zones, sprawling across the land and extensive ring roads around the original city centre. Although large-scale construction indeed activates local economic growth and partly improves people's living conditions, the subsequent energy demand is dramatically growing as are costs due to long distance trips and increasing car ownership. While China's government has made efforts in energy efficiency and conservation of transport system, the extensive development of electrical cars does not seem realistic in the near future.

Establishing a sustainable transportation system without more deterioration in the environment and more risks to energy conservation would be a challenging task for

China. According to Litman (2001), sustainable transportation can be evaluated by measuring automobile dependency: the greater the dependence on automobiles, the less sustainable the transportation system, and vice versa. Therefore, low carbon travel, such as walking and cycling, should be considered as critical determinants for a sustainable urban transport system. In fact, the previous urban form in China (e.g. the work unit) with high level active mode accessibility provides promising prospects for achieving sustainable urban transportation as opposed to increasing reliance on private car development.

8. Path-break 100-year Vision

Finding new ways to design cities or devise new lifestyles that can perform with low carbon emissions is a challenging issue, typically involving imagination about future cities. Sometimes it is enlightening to look to the past to learn about system dynamics that have been supportive of human being's survival and development. This chapter assumes that the work unit design was resumed as the basic organisational cell for the future vision of Beijing after 100 years. Besides the co-existence of workplaces and housing, the layout of diversified shopping facilities which resemble a conventional work unit in the city centre of Beijing is illustrated as a model for future shopping development.

8.1 Model

Based on a travel survey about carbon emissions of inhabitants' daily travel behaviour in Beijing, Ma et al. (2011) pointed out that the probability of motorised travel (including car driving and transit) in existing work units of Beijing is about 33%, showing a relatively lower carbon emission potential compared to non-work unit groups. Since the work units are still in existence (see Figure 5-4) and functioning well in terms of low carbon travel, in this paper the conception of 'new urban village' on the basis of previously dominant work unit form was employed as the idealistic model for future visions of Beijing. It is hypothesised that the urban sprawl trend would be replaced by concentrated land use and population in the future. The urban village community design can serve both the traditional purpose of housing workers close to the centres of production, and provide access to goods and services, education and recreation. It can also provide the hub for access to subways and light rail lines for access to other urban villages, and the city centre and parks. A descriptive storyline about the future urban village is outlined below:

- The air is clean, no personal petrol cars and no diesel buses
- People are healthy and productive, with access to work, shopping and social activities
- Oil resources are merely used for delivering important materials, not personal transport
- The city is full of people, but not congested with individual vehicles

For this purpose, a matrix of 1km×1km cellular composite urban villages with a total built area of 1000 km^2 was modelled with the assistance of ArcGIS system (see Figure 8-1). In each urban village cell, the residences are surrounded by workplaces, shops and recreation parks; the transport system is mainly composed of local streets and cycle ways. The inter-region and long-distance trips are connected by light rail or tram networks along the existing corridor roads.

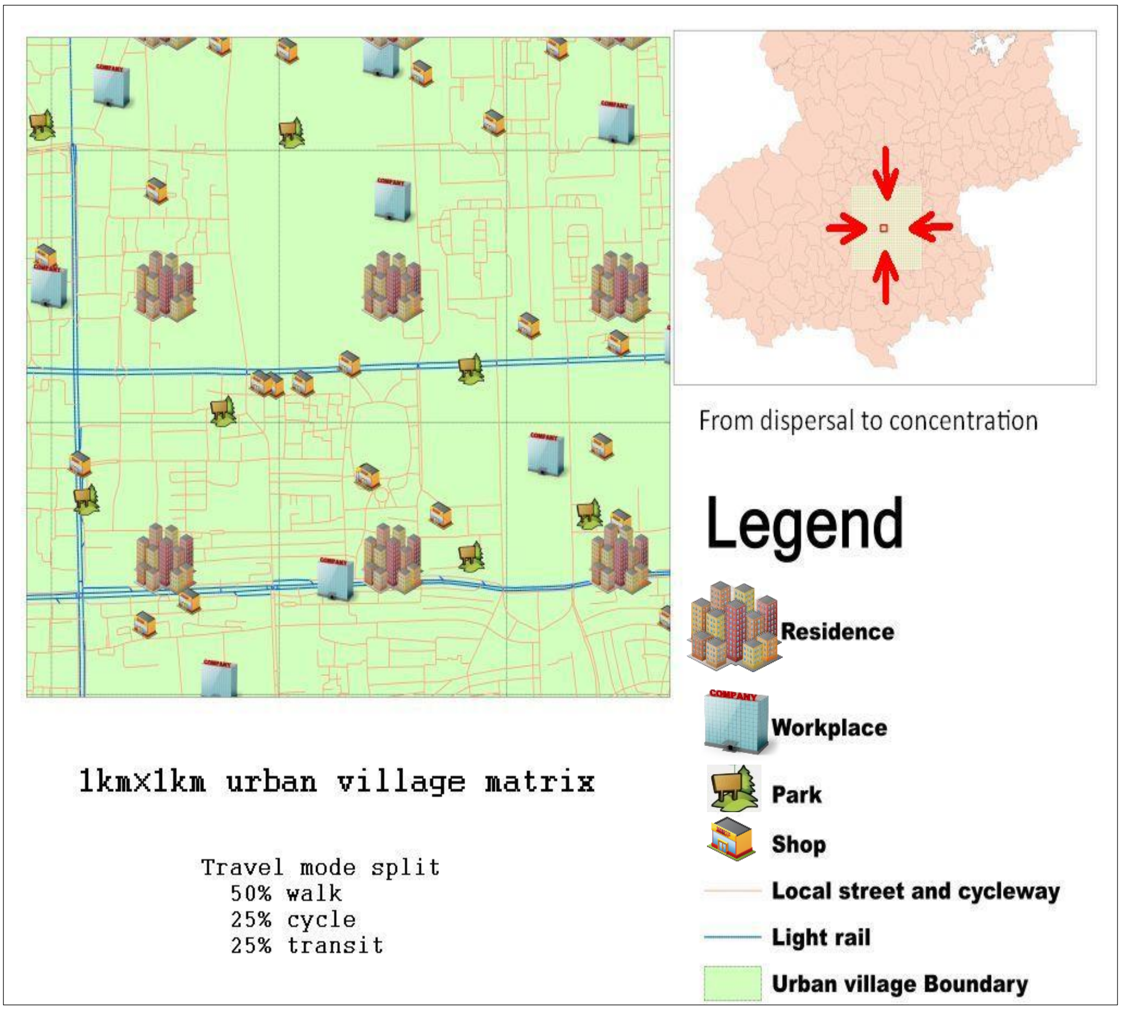


Figure 8-1 The envisioned map of future Beijing with new urban village style

8.2 Employment layout

The projected population in each cell after 100 years was estimated using the linear growth model of population prediction assuming the distribution remains the same as the present. Accordingly, the distance-based working population distribution for a cell *i* can be expressed as follows:

$$CP_i^{d_n} = r^{d_n} P_i \; (d_n = 2,5,10, \ldots \ldots km) \quad \text{(8-1)}$$

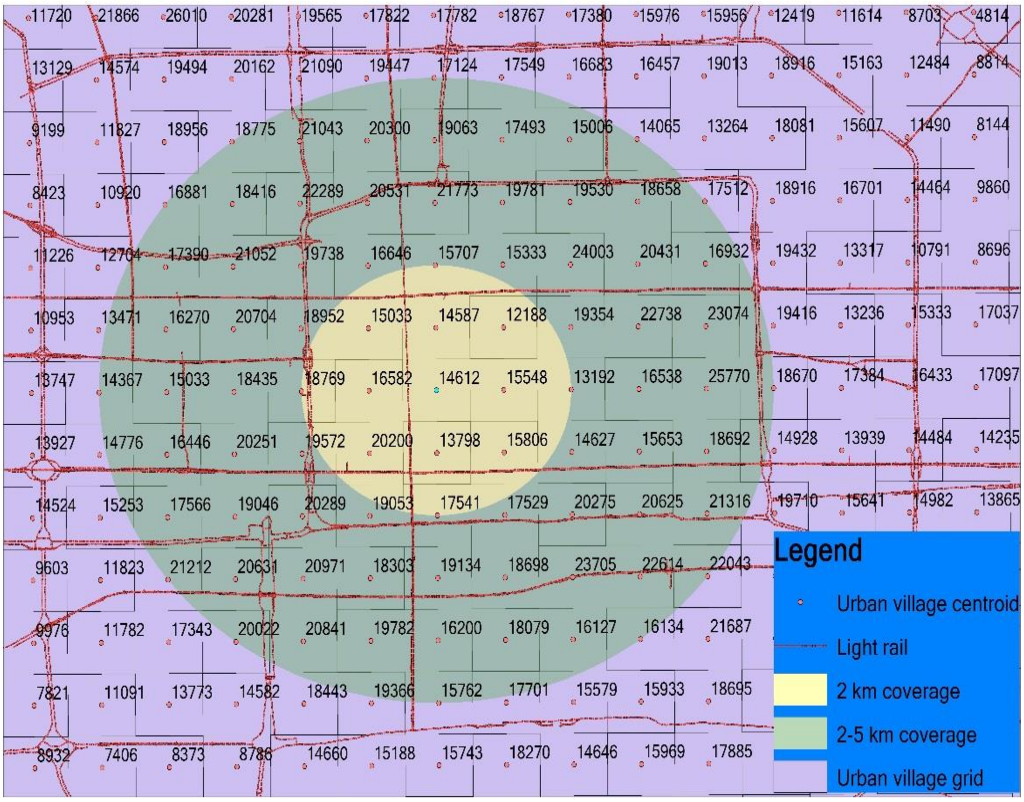
where $CP_i^{d_n}$ is the projected working population from cell *i* in distance bin d_n, r^{d_n} is the proportion set by the user, P_i is the projected number of working population of cell *i*, specified as 70% of the total population in this research. The value of r^{d_n} in the future can be arbitrarily assigned as appropriate. Here it is assumed that

$$\begin{cases} r^{d_1} = 50\% \text{ means 50\% commuters work within 2 km within travel mode by walking} \\ r^{d_2} = 25\% \text{ means 25\% commuters work between 2-5 km with travel mode by bike} \\ r^{d_3} = 25\% \text{ means 25\% commuters take transit for work if commuting distance>5 km} \end{cases}$$

As such the projected employment distribution for each cell can be simulated based on the assumptions above. For each cell, the buffer areas in different distance bins can be mapped with the ArcGIS system, then the employment assignment was coded in Python script following the steps below:

- In 2 km buffer area, randomly assign 50% of the working population into the covered cells.
- In 2~5 km buffer area, randomly assign 25% of the working population into the covered cells.
- The remaining working population were randomly assigned into other cells.

For each iteration, the assigned employment in each cell was accumulated, ultimately a random employment distribution map of urban villages was formed, as illustrated in Figure 8-2.



Note: the number in each cell signifies the projected employment opportunities in the future

Figure 8-2 A random employment assignment map of a study cell (blue dot) in the city centre with a population of 15,424 in the future

8.3 Shopping layout

Based on literature reviews and GIS data, the layout of shopping facilities around a work unit is designated as the model for future shopping distribution in a new urban village. The shopping layout around Sanlihe work unit area was taken as an example to embody the proposed shopping facilities distribution in the future. In this research, the definition of accessibility from Hansen (1959) was used by counting the number of activities (e.g. shops) available at a given distance from an origin (e.g. the home).

$$A_w^d = N_w^d$$

where *W* means the weight of shopping facility, *d* means the distance bin from origin. N_w^d denotes the number of shopping facilities with weight *W* within different distance bins. For the sake of simplicity, only the walking distance (2 km) is considered in this research. In fact, according to the travel survey by Jian et al. (2007), the shopping distance for essential and necessary needs in Beijing is less than 2 km regardless of geographical location, and personal attributes of residents. With the assistance of ArcGIS, an example of accessibility calculation for Sanlihe work unit is illustrated in Figure 8-3. The summarised results for different shopping facilities based on the essentiality theory are listed in Table 8-1.

Table 8-1 shopping facility statistics around Yuetan sub-district

Shopping facility classification	Shopping facility with essential needs (grocery store, supermarket, department store)	Shopping facility with necessary needs (computers, furniture, household appliances)	Shopping facility with optional needs (antiques, jewellery, pets, flowers)
Amount	285	10	101

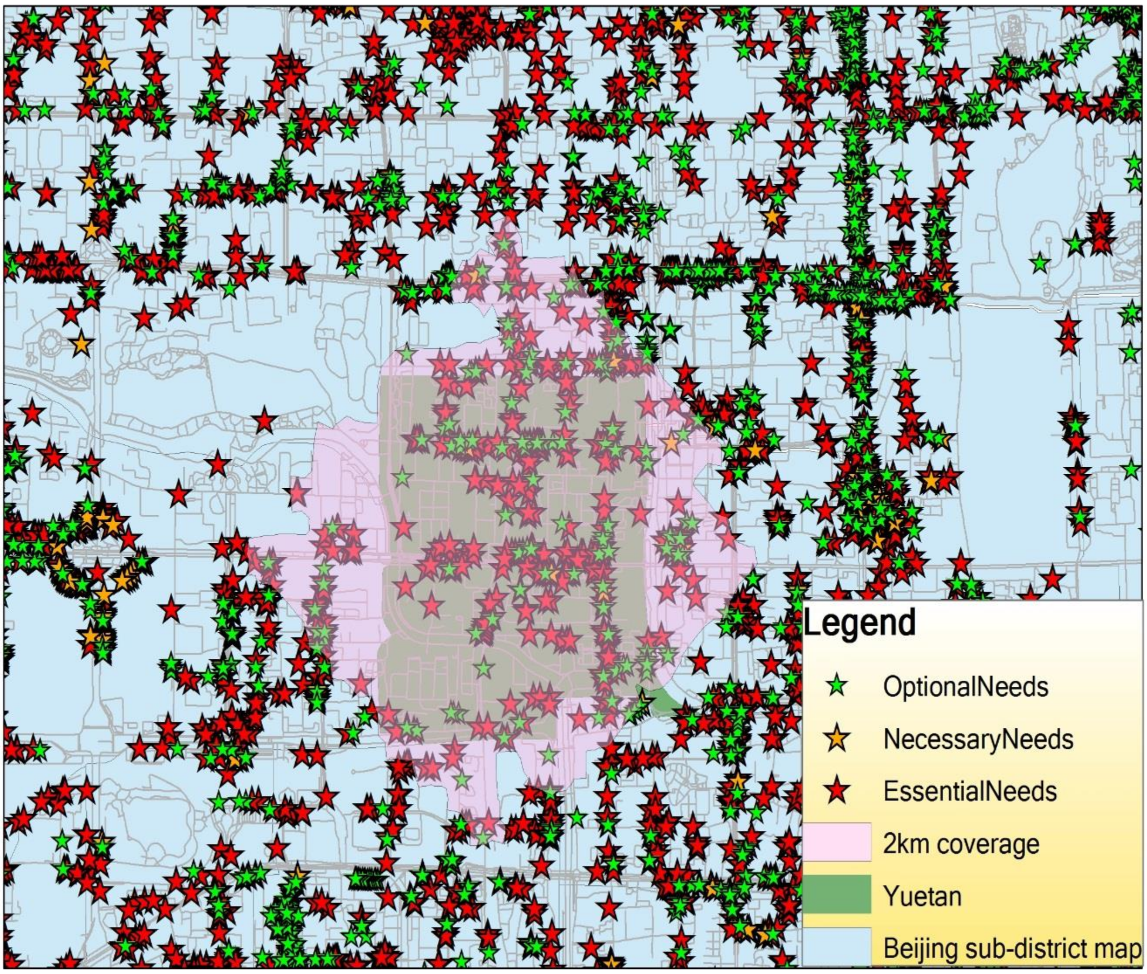


Figure 8-3 Shopping facility distribution around a work unit in the city centre as a future shopping layout for a new urban village

8.4 Concluding discussion

In order to mitigate risks that might severely affect traveller activity participation, such as future oil shortages or car restriction policies, the subsistence activities (e.g. work and shopping trips) should be done as close to residences as possible. In this connection, a new urban village model based on the conventional work unit design was presented in this chapter. By doing so, the urban village can serve both the traditional purpose of housing workers close to the centres of production, and providing access to goods and services, education and recreation. It can also provide the hub for access to subways and light rail lines for access to other work units, and the city centre and parks. Apart from that, multiple generations of families with different incomes and different jobs could live in the same work unit to preserve the social benefits of care of the elderly and children by family members.

For this purpose, more staff apartments should be built in each cell, requiring a range of housing costs and amenities. Considering the concentration of built areas in the future, mixed land use with a high density of population and employment might be needed as a result.

9. Back-casting

Back-casting is an approach that analyses differences between the desired future visions and the present trends in terms of various influencing factors. For transport energy systems, the back-casting procedures analyse the adaptive capacity of the end use sectors and the infrastructure and behavioural aspects that are fundamentally different in the path-break concept and how they could be modified from the present to develop in the direction of the path-break. Because of the differences in the nature of travel activities, this chapter presents the measurement to calculate the employment gap and shopping gap separately. It then integrates the results with a number of GIS techniques to identify the most resilient and most vulnerable areas.

9.1 Employment gap identification

For employment activities, here we employed the difference value of local employment for each cell between the projected employment distribution and the current situation as the indicator to demonstrate the employment gap and how employment distribution should be changed to meet the required target, which is expressed as below:

$$D_i^E = {E_i^C}/{E_i^P} \qquad (9\text{-}1)$$

where E_i^C are the current employment opportunities in cell *i*, which can be derived from official datasets as shown in Figure 9-1. E_i^P are the projected employment opportunities in cell *i*, which has been calculated in Section 8.2. Then the difference between the future employment distribution and the present one was mapped with interpolation techniques by ArcGIS system, as illustrated in Figure 9-2.

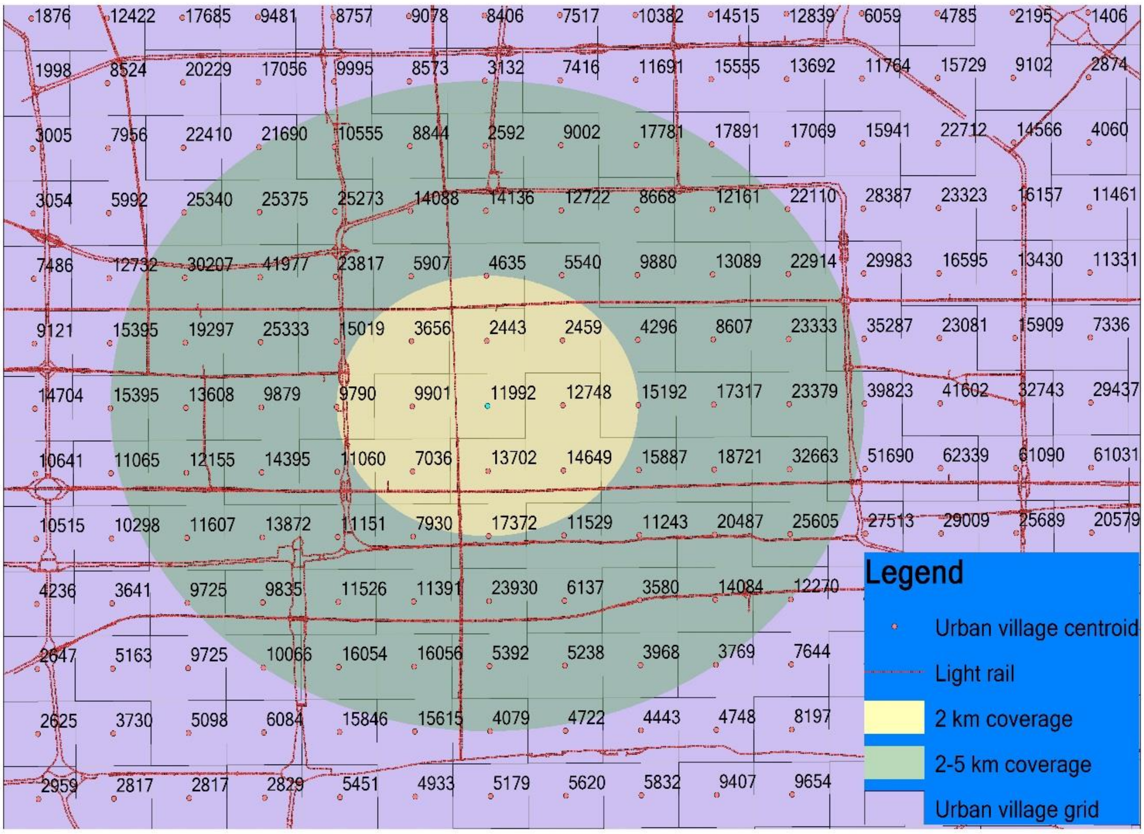


Figure 9-1 Current employment distribution derived from official statistics

Not surprisingly, it can be seen that the suburban areas are lacking in the supply of employment, indicating a great jobs-housing imbalance during urban expansion of Beijing city. Some workplaces would need to be created in these areas to achieve the objective of developing a new urban village in Beijing. Also, the traditional employment catchments such as CBD and Silicon Valley of Beijing have much higher employment supplies compared to local residents, thereby attracting large numbers of long-distance commute trips around the city. If these employment centres have to be retained, the transit service to these areas must be improved or strengthened to accommodate the possible large-scale commute flows. The yellow and orange areas on the map could be the best places for developing a new urban village pattern as the local employment opportunities basically match the job requirements for future inhabitants living in these areas.

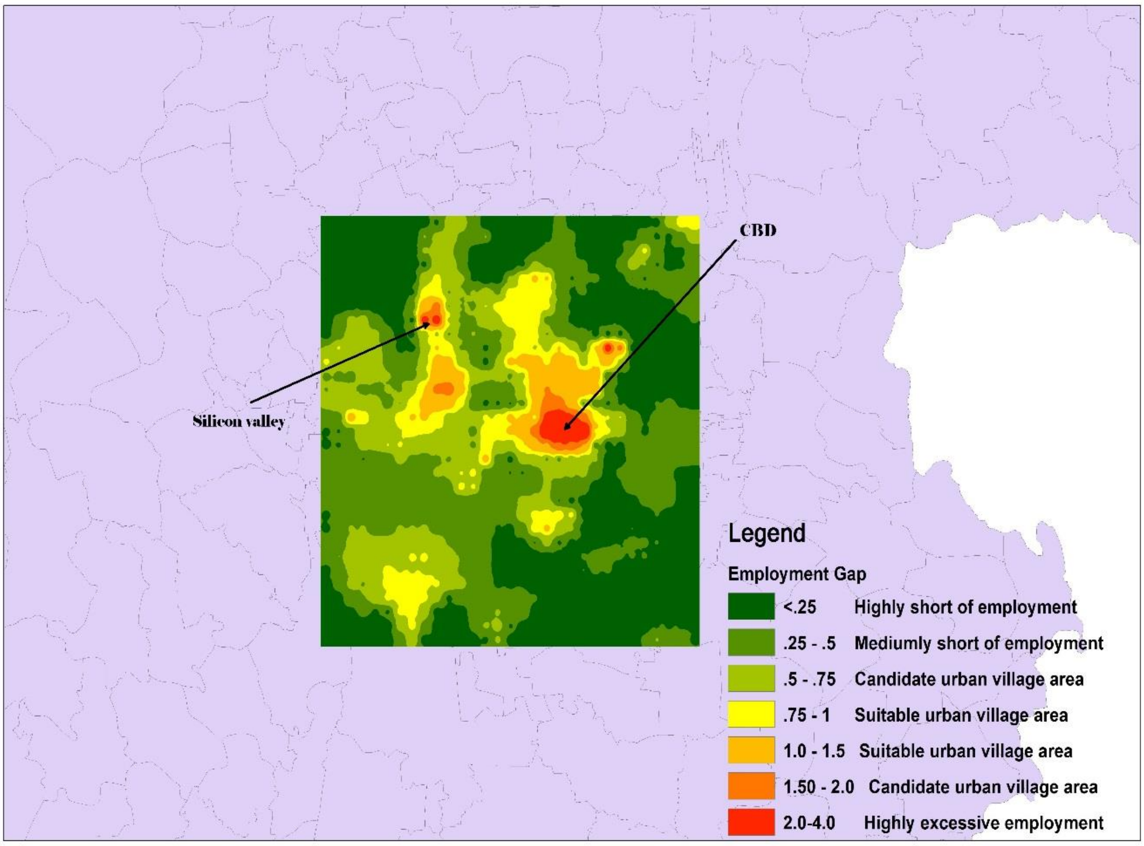


Figure 9-2 The geography of employment gap within walkable distance with associated ranking

9.2 Shopping gap identification

For shopping activities, we employed the comprehensive difference value of accessibility to different shopping needs within 2 km of the projected shopping facilities distribution and the current situation to demonstrate the shopping gap and how shopping facilities in the future should be placed to meet the required target, which is formulated as follows:

$$D_i^S=0.5 * S_E^C/S_E^p+0.3* S_N^C/S_N^P+0.2*S_O^c/S_O^P \qquad (9\text{-}2)$$

where D_i^S is the comprehensive difference value for cell *i*. S_E^C is the current number of shopping facilities for essential needs, S_E^p is the projected number of shopping facilities for essential needs in the future. Likewise, the calculation of shopping facilities for necessary needs and optional needs is carried on respectively following this way. The weight for essential, necessary and optional needs is assigned as 0.5, 0.3 and 0.2 respectively. In the end, the difference between the future and present shopping layout was mapped with interpolation techniques by ArcGIS system, as illustrated in Figure 9-3. It can be seen that the shopping gap generally presents a gradual decay trend with the increase of distance to the city centre. The traditional shopping areas around the city centre and CBD have prosperous retail services with the highest value of difference, the silicon valley of Beijing (Zhongguancun) also possessing a large number of shopping facilities since many IT companies, as well as employable population and universities are located there. In the future, the shopping development should be largely placed in the green areas, as shown in the figure, to build more diversified grocery stores or supermarkets that can serve people with more essential and necessary needs.

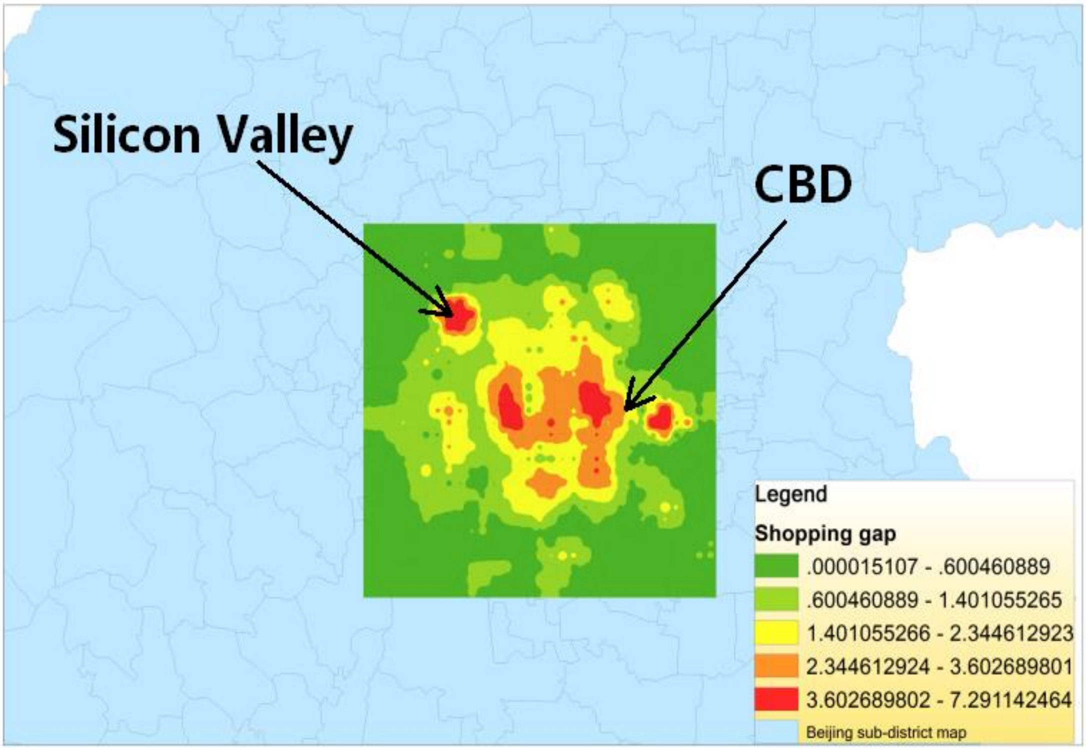


Figure 9-3 The geography of the shopping gap within walkable distances with associated classification

9.3 Integrated back-casting

9.3.1 Future re-development hierarchy

If a region has a good potential in terms of sufficient employment opportunities, diversified shopping facilities and convenient transit system, it would be highly resilient to fossil fuel disruption or car driving restrictions. Accordingly, based on the developed maps of employment gaps and shopping gaps, the site selection for the future re-development area could be identified as a result. In this research the evaluation indicators for future development are mainly centred on walking accessibility to work, shopping and transit (corridor). For the sake of calculation, all the values in these maps have to be transformed into dimensionless numbers, which can be done using the Reclassify tool of the ArcGIS system.

Work gap reclassification: The value of the employment gap within walking distance should not be extremely high or low. In this connection, the gap between 0.75-1.5 is reclassified as the highest new value; the dimensionless transformation is defined in Table 9-1; the raster map of the employment gap with new values is shown in Figure 9-4.

Table 9-1 Evaluation criterion for work gap

Old values	New values
0.75-1.5	4
1.5-2.0 or 0.5-0.75	3
0.25-0.5 or 2-4	2
<0.25	1

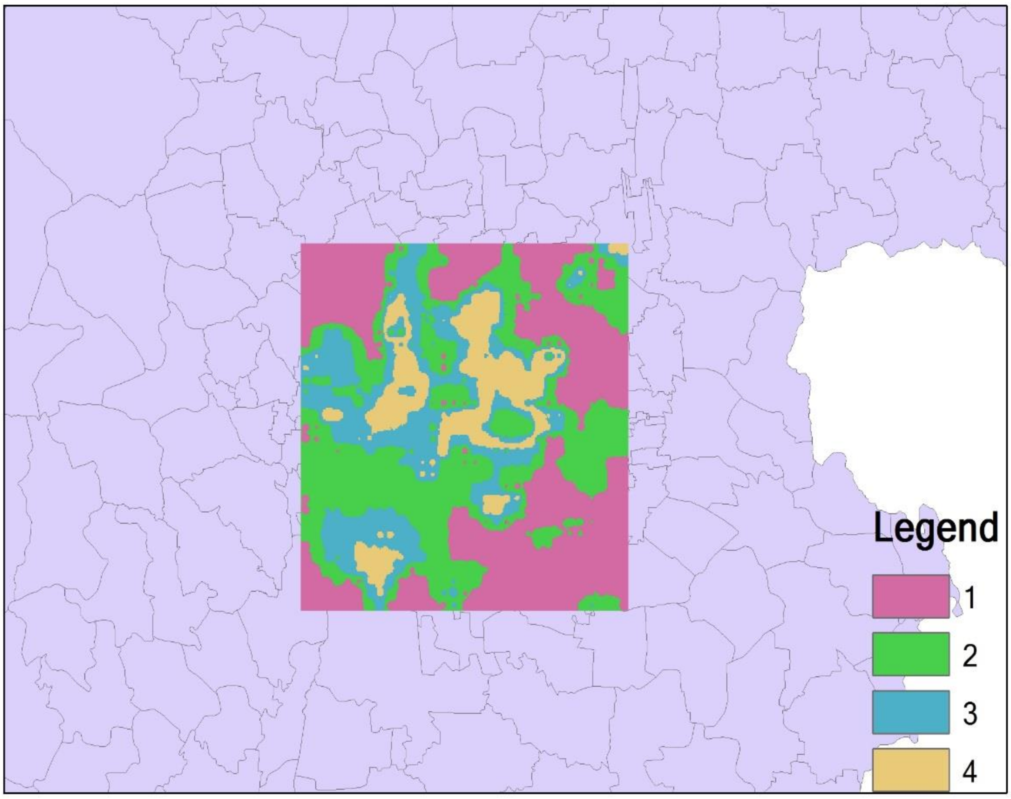


Figure 9-4 Reclassification for employment gap

Shop gap reclassification: The value of the shopping gap within walking distance is reclassified in proportion to the order of old values, which says, the higher the gap, the higher the new value, which is illustrated in Figure 9-5. The raster map of the shopping gap with new values is shown in Figure 9-6.

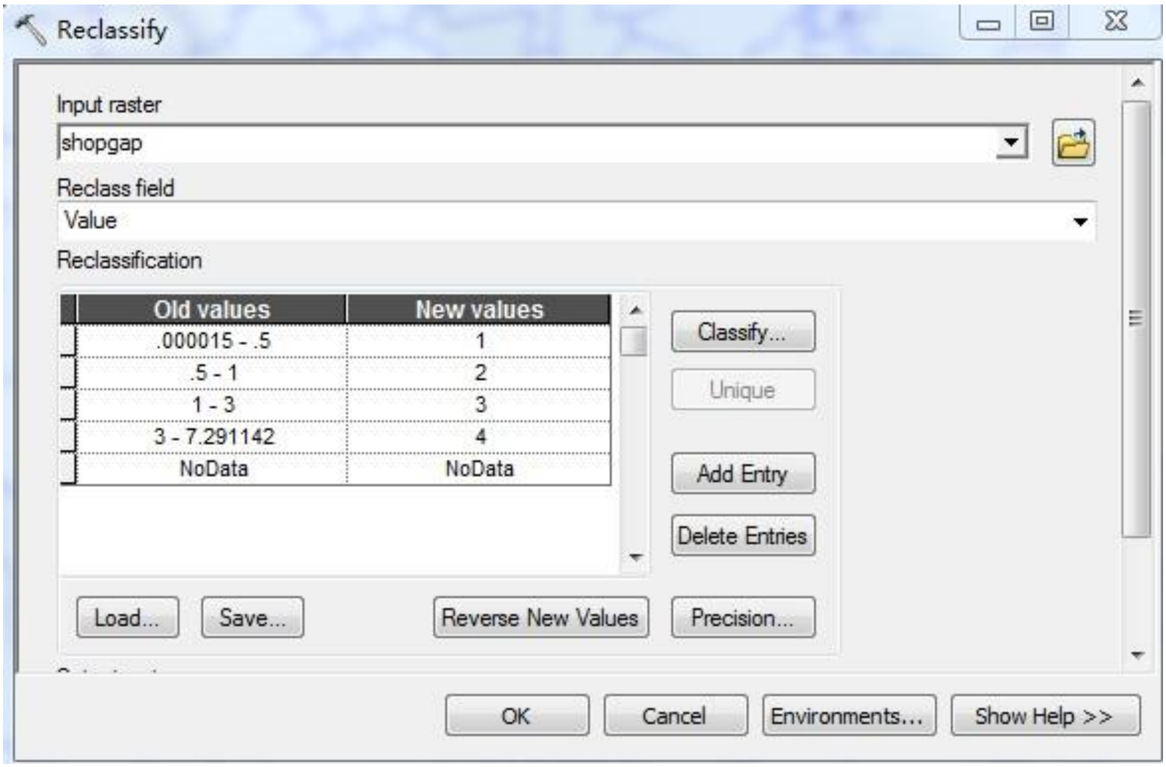


Figure 9-5 A screenshot of the shopping reclassification process

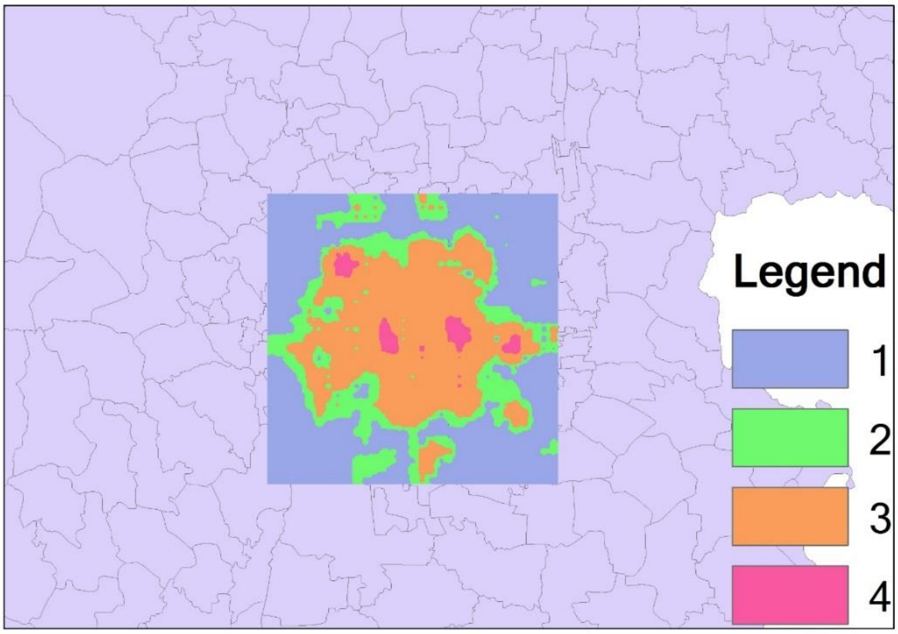


Figure 9-6 Reclassification outcome of the shopping gap in Beijing

Transit accessibility reclassification: the evaluation criteria for transit accessibility are tabulated in a table based on the distance to the corridor roads. After generating multiple buffer areas along the corridor roads (see Figure 9-7), the reclassification for transit accessibility following the rules in Table 9-2 was developed as shown in Figure 9-8.

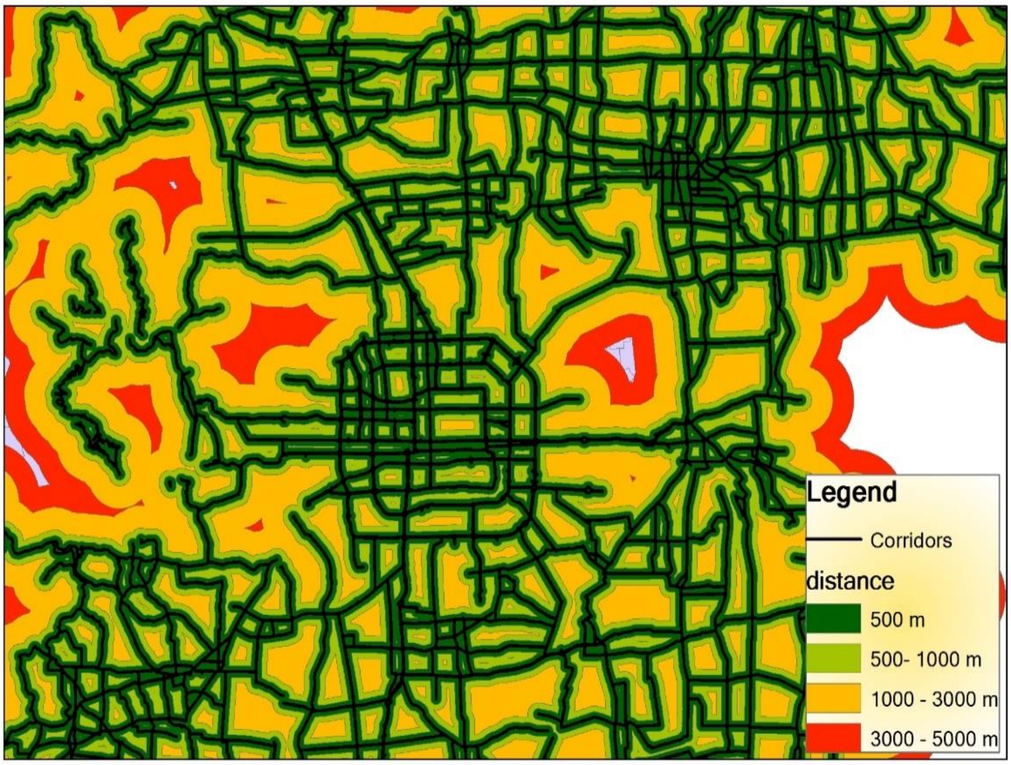


Figure 9-7 Multiple buffer areas along the corridor roads

Table 9-2 Evaluation criteria for transit system

	Classification	New values
Multiple buffer areas along the corridor roads	0-500 meters to corridor roads	4
	500-1000 meters to corridor roads	3
	1000-3000 meters to corridor roads	2
	3000-5000 meters to corridor roads	1

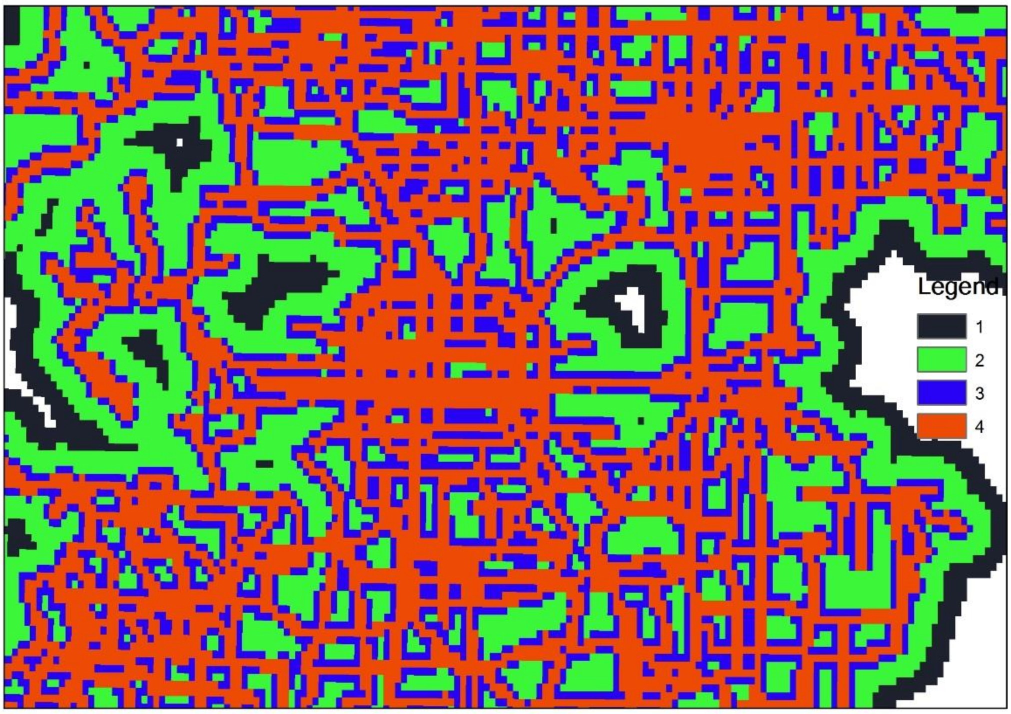


Figure 9-8 Reclassification outcome for transit system of Beijing

9.3.2 Integration

Hitherto, all the dimensionless assignments have been completed. Thus, the combined result of the employment gap, the shopping gap plus the transit accessibility gap can be calculated according to the following equation:

‘Reclassified_employ’+’Reclassified_shop’+’Reclassified_transit’

(Note: In this research, the weight for each factor is set at 1)

Using the map algebra tool (see Figure 9-9) in the ArcGIS system, the distribution map of synthesised value for the new urban village of Beijing was developed as shown in Figure 9-10. The most vulnerable areas (value=3) that might be highly reliant on private cars are highlighted with blue circles. For these regions, more shopping facilities, employment opportunities as well as an extended transit system should be created to meet future requirements. The most resilient areas that have a theoretical jobs-housing balance, prosperous shopping service and convenient transit system are highlighted with black circles. If the new urban village pattern was adopted in the future, these areas would be the best opportunities for the first shift projects. For instance, redeveloping some work units in these regions so that the new generation of employees can live and work nearby if the employment facilities in these regions remain in the future.

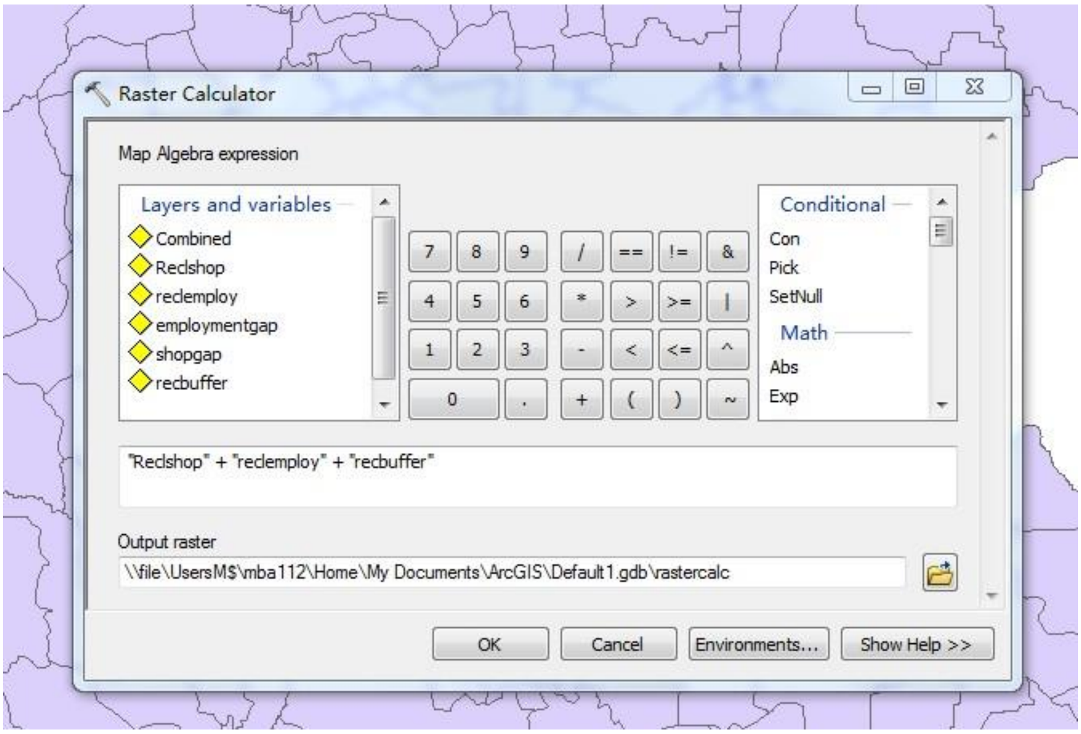


Figure 9-9 A screenshot of map algebra for integration

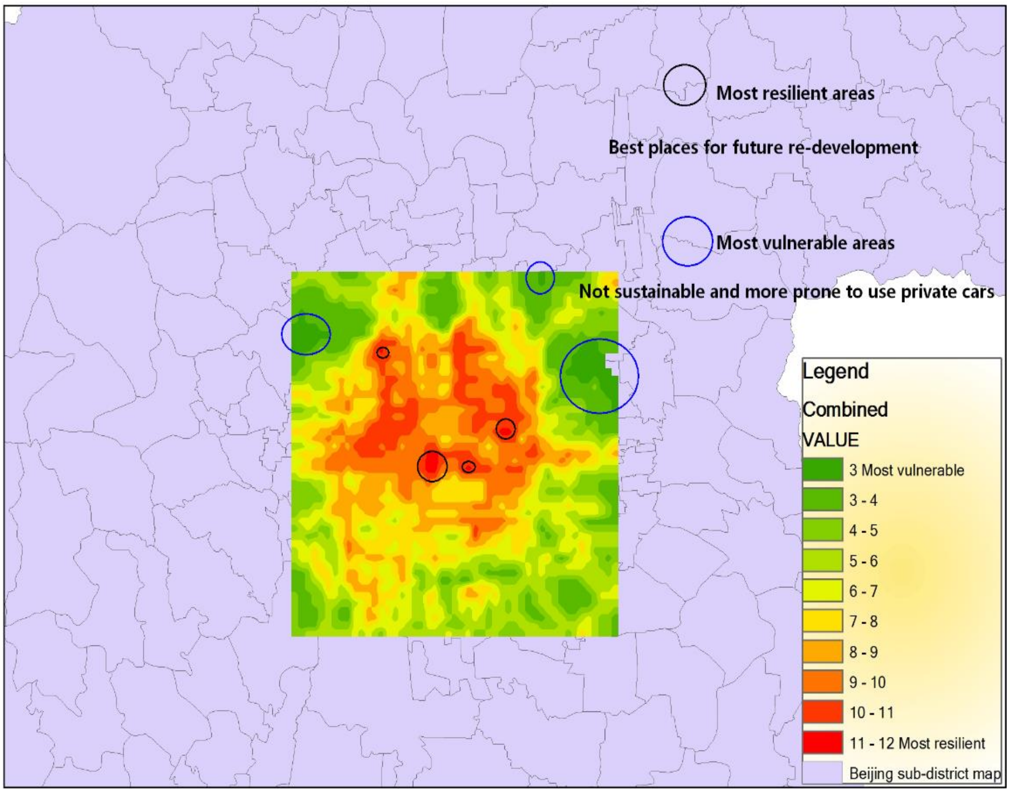


Figure 9-10 Integrated gap of Beijing for future development

9.4 Concluding discussion

GIS-based Back-casting is an innovative method for the development and analysis of normative scenarios by working backwards from the envisioned future to the present situation. As illustrated in Chapter 8, the new urban village, following the work unit design, was proposed to be the basic organisational cell for future Beijing after 100 years, by which time adequate employment opportunities, diversified shops and a convenient transit system could be accessible within walking and cycling distances. After calculating the differences in employment opportunities, shopping facilities and transit accessibilities, the integrated output was mapped with the assistance of the ArcGIS system to illustrate the gaps between the projected scenarios and the present status, with which the most vulnerable and resilient areas could be identified.

The model about the future vision after 100 years and the attendant back-casting analysis presented in Chapters 8 and 9 are not necessarily suggested as the future target, but represent a potential way of achieving low energy intensity transportation systems. Considering the fact that the work unit has been prevalent in Chinese cities, it is appropriate to take the work unit design as the prototype for future urban village lifestyles. The major concerns for the feasibility of the new urban village development lie in the construction costs of building more work units and the affordability for medium-low employees taking into account the high land prices in Beijing. Apart from that, the old-fashioned apartments with 4-5 storeys in conventional work unit areas have to be redeveloped to accommodate more population due to the proposed concentration process.

10. Trigger event and transition project

Existing systems have great inertia in investment, belief and behaviour. But they can also change very quickly through an effective change project or when a crisis occurs. The trigger event is the engineered change project that is designed to initiate future transition projects. In a transport energy system, the trigger events could be caused by an energy crisis or a policy target with the shift away from heavy reliance on private cars. Since 2008, Beijing municipal government has imposed the "odd-even" license plate restrictions to contain the rapid growth of car use and cope with the increasingly serious congestion and pollution, which means all private cars are banned from use every other day. To this end, some car-driving commuters have to change their travel patterns to maintain commuting activity participation. In addition, it has been postulated by the municipal government that the cycling travel mode share of Beijing should increase to 20% in the next few decades (BMCT, 2015). Some analysis tools for the transition project, including SATS, have been introduced in Chapter 4. This chapter first expands on the above measurements with more detail, then taking one area in the city centre and another one in Beijing suburb to initiate a transition project on the assumption that the rise of cycling mode share at 20% would be achieved in the next decades. This indicates how much potentially cyclable trips could be generated by forgoing car trips under different development visions as well as the relative merits of development scenarios for decision-making.

10.1 Methodology

The flowchart of Strategic analysis for Transport System is presented in Figure 10-1. The detailed procedures of the methodology are described as follows:

Step 1: audits, surveys and data analysis

Firstly, the necessary surveys of the study region, the relating demography and the geography, such as population, employment, land use, and building structures are required to characterise the current commute activities in accordance with the rationale of transition engineering. Based on the previously developed commute model, all the parameters of sub-districts regarding the commuting distance distribution have been calculated.

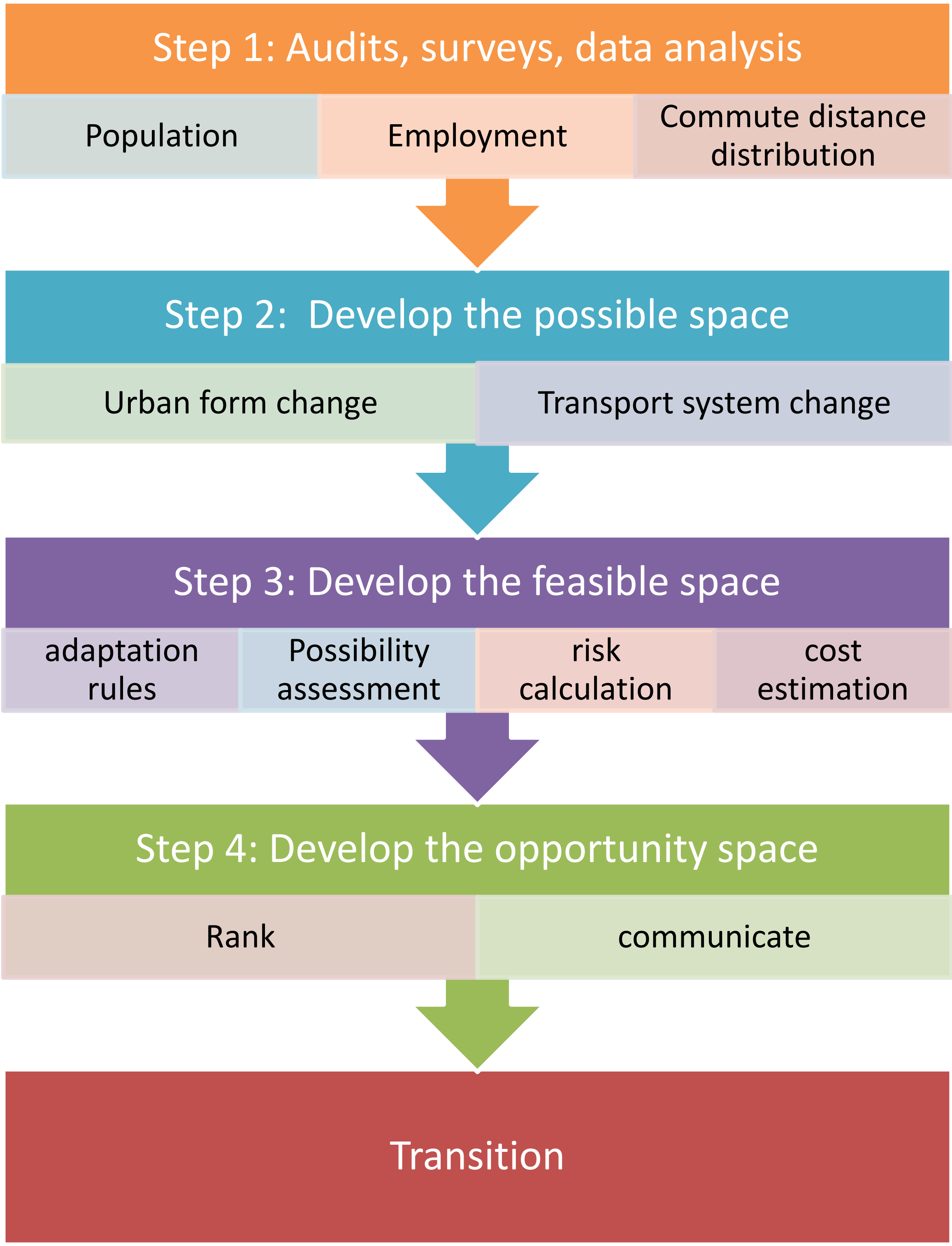


Figure 10-1 Flowchart of SATS analysis

Step 2: develop the possible space

Two sets of development scenarios that are possibly conducive to the rise of cycling potential were designated in this research. Urban form or land use changes are represented by Business as usual, cycleway development and new urban village style, transport system changes consist of BAU and electric-bike promotion scenarios. For the sake of illustration, an example of possible space is shown in Table 10-1.

Table 10-1 Development options in favour of cycling trips

		Urban form, land use changes		
Transport system changes	*Target: 20% cycle mode share*	Current	Cycle way infrastructure	New urban village
	Business as usual	Scenario 1: • No change to current system • Voluntary mode shift	Scenario 2: • Cycling promotion • Active mode shift to cycling	Scenario 3: • Work closer to home
	Electric bike *promotion*	Scenario 4: Electric bike promotion without corresponding infrastructure	Scenario 5: Electric bike with cycling environment improvement	Scenario 6: • Work closer to home

Step 3: develop the feasible space

Cycle-oriented adaptation rules

In the light of the uncertainty of human behaviour along with the changing environment, and the limitations for obtaining the detailed travel survey data in Beijing about human travel behaviour changes when faced with restricted car use, it is hypothesised in this paper that the proportion of car trips that can be reduced in each distance bin is random. However, in practice the likelihood of travel by bicycle or e-bike is highly sensitive to travel distance, typically the further the distance, the lower the bike mode is. For instance, a travel survey of commuters living in Beijing about their travel mode choice, the travel distance was carried out by Ming and John (2016). The obtained data shows that the majority of cycling distances are within 5 km, and less than 20% of cyclists travel more than 5 km (see Figure 10-2). By contrast, the fitting result based on a travel survey conducted by Mao et al. (2007) shows that the travel distance curve of e-bikes exhibits quadratic-like characteristics peaking at around 8 km (see Figure 10-3). Thus, it can be inferred that the bicycle can perform as a substitute for short-distance (<5 km) car trips, whereas the e-bike is more advantageous in medium-distance (5-10 km) trips. In the aspect of relocation behaviour, David (2014) pointed out that the mover rate in United States between 2012 and 2013 was about 11%, in which around 20% of people migrate for job-related reasons. Therefore, based on the international literature and practical situations in China, the limitation for adaptation options needs to be considered; consequently, the change limits for different development scenarios are reasonably defined, as shown in Table 10-2.

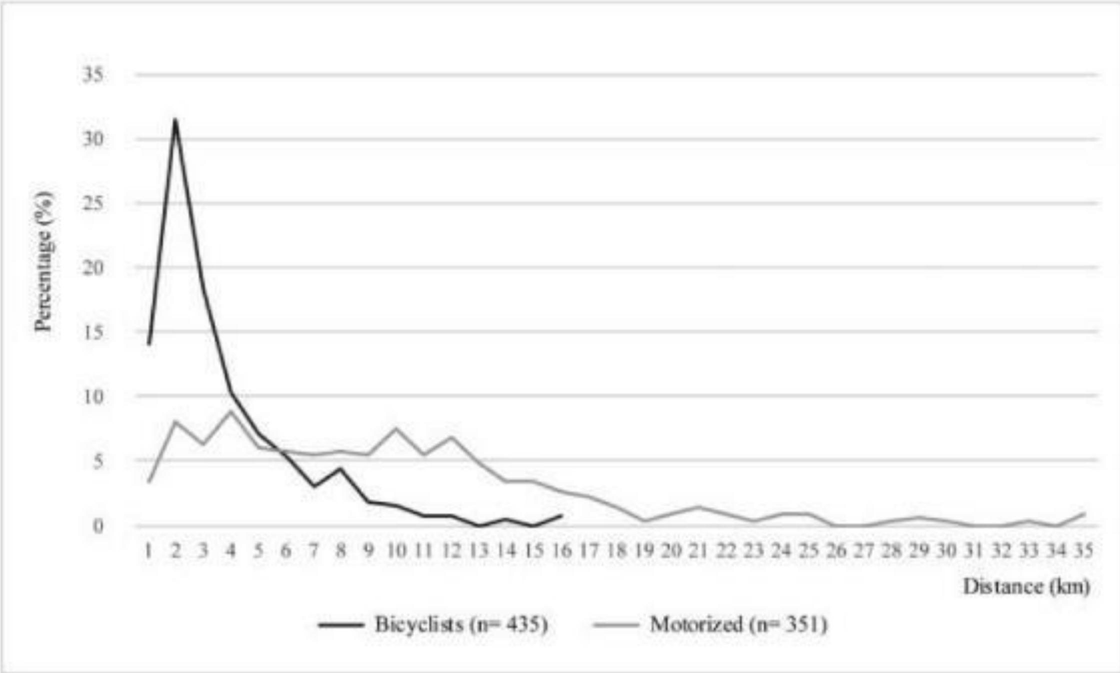


Figure 10-2 Distance distribution of bicyclists and motorised commuters in Beijing

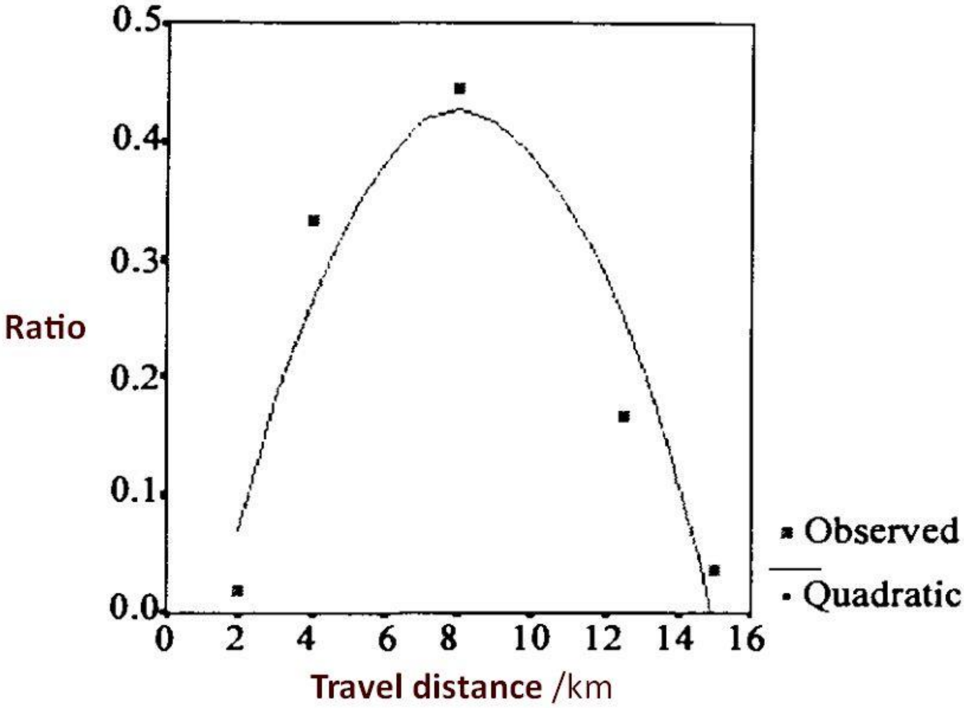


Figure 10-3 Distance-based travel characteristics of E-bike

Table 10-2 Car trip change limitations for different development scenarios based on distance bins

Adaptation options	**Maximum transition probability of car trips**			
	d_1 (0-2km)	d_2 (2-5km)	d_3 (5-10km)	d_4 (>10km)
Scenario 1 **BAU**	Mode shift: 75% Move closer:0 Change job:0	Mode shift:20% Move closer: 0 Change job:0	Mode shift:5% Move closer:5% Change job:0	Mode shift:0 Move closer:10% Change job:5%
Scenario 2 **Cycle way infrastructure**	Mode shift:100% Move closer:0 Change job:0	Mode shift:30% Move closer:0 Change job:0	Mode shift:10% Move closer: 10% Change job:0	Mode shift:5% Move closer: 10% Change job: 5%
Scenario 3 **Work unit design**	Mode shift:75% Move closer: 0 Change job:0	Mode shift:20% Move closer: 0 Change job:0	Mode shift:5% Move closer: 10% Change job:0	Mode shift:0 Move closer:10% Change job:5%
Scenario 4 **Electric-bike use only**	Mode shift:100% Move closer:0 Change job:0	Mode shift:50% Move closer:0 Change job:0	Mode shift:30% Move closer: 5% Change job:0	Mode shift:20% Move closer: 5% Change job:5%

Scenario 5 **Electric-bike promotion with associated infrastructure**	Mode shift:100% Move closer:0 Change job:0	Mode shift:75% Move closer:0 Change job:0	Mode shift:50% Move closer:0 Change job:0	Mode shift:30% Move closer: 5% Change job:5%
Scenario 6 **Work unit design with electric penetration**	Mode shift:100% Move closer: 0 Change job:0	Mode shift:50% Move closer: 0 Change job:0	Mode shift:30% Move closer: 10% Change job:0	Mode shift:20% Move closer:10% Change job:5%

Adaptation options priority

The individual adaptation options under different visions are listed in Table 10-2, and the adaptation sequence is dictated as below. Once the current distance-resolved car trip characteristics for the study area are obtained, then the possible car driving reductions in a certain distance bin are randomly made and the commuters would change their travel patterns following the steps as below. At each step, the generated cycling mode share is calculated and compared with the cycle mode target. If the target can be reached, then it is recorded. In addition, the number and type of changes are recorded for subsequent impact analysis and cost estimation.

1. Work unit choice (if available). A fraction of employees working in the study region move into work units until all the work units supplied are fully filled.

2. Mode shift. Car trips by local residents are randomly selected and shifted to cycle or e-bike mode according to the following rules:
    - Mode shift to bike or e-bike in 0-2km (d_1) car trips until the limit set by the user is achieved.
    - Mode shift to bike or e-bike in 2-5 km (d_2) car trips until the limit set by the user is achieved.
    - Mode shift to bike or e-bike in 5-10km (d_3) car trips until the limit set by the user is achieved.

2. Relocation. For long distance (>5km) car trips, randomly select:

- A fraction of local residents move out to live closer to their workplaces until the limit set by the user is achieved.
- A fraction of local residents have to change their careers to find workplaces closer to home until the limit set by the user is reached.

Repeat these procedures 10,000 times to compute the number of iterations that meet the required target. The algorithm used in Python script is illustrated as in Figure 10-4.

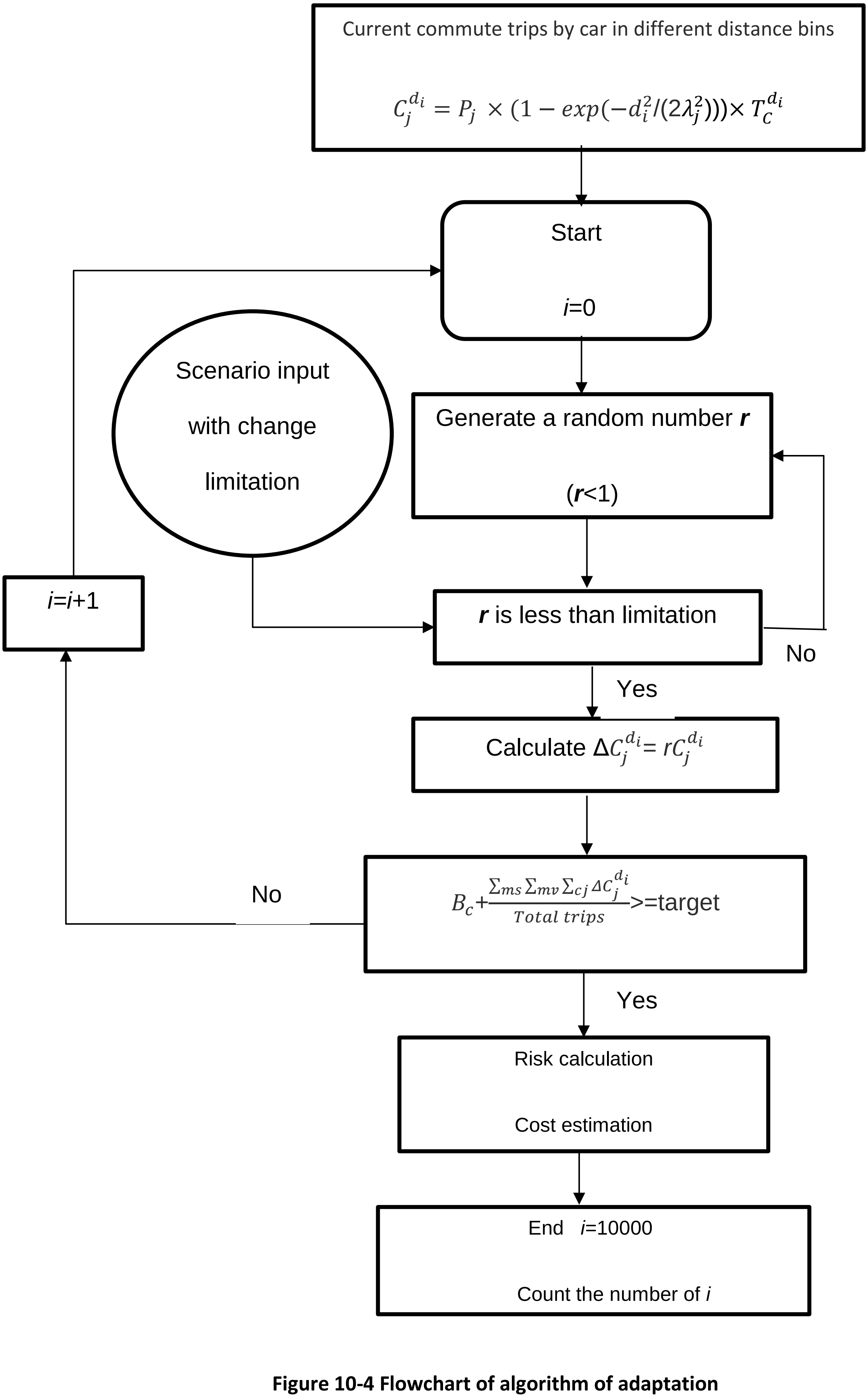


Figure 10-4 Flowchart of algorithm of adaptation

where *r* is a random decimal with the limitation as assigned in Table 3. $TC_j^{d_i}$ is the changed car trips by local residents. $C_j^{d_i}$ is the current number of car trips in different distance bins, which can be calculated from equation (5). ΔE_j are the added residents who shifted from local employment E_j thanks to the work unit provision, *p* is an appropriate ratio of work unit provision for local employees, which was assigned with 3% and 5% for the study region respectively (see Table 2). B_c is the current cycle mode share (12.6%, see Figure 5), $\sum_{ms}\sum_{mv}\sum_{c} TC_j^{d_i}$ is the sum of generated cycling trips through mode shifting, moving or changing job. After running 10,000 iterations with the successful number of *n*, the probability to achieve the desired target under each development scenario is calculated with the following equation:

$$P=n/10000 \qquad (10\text{-}1)$$

Impact analysis

The car trip changes in each distance bin are used to calculate the risk to individual level commute activity participation under different development scenarios. In order to quantify the impact of car trip changes on personal commuting comfort and wellbeing, some weighting metrics are defined, as presented in Table 10-3. The risk weight of an e-bike is assigned bigger than a bicycle taking into account the associated safety issues and embedded energy consumption entailed by the use of the electric bike. Then the method for calculating the degree of risk is presented in equation (10):

$$RI=\sum_{n}^{10000} TC_j^{d_i} * W * d_i \ /10000 \qquad (10\text{-}2)$$

where *RI* is the average risk index of car trips change in order to achieve the specified target, $TC_j^{d_i}$ is the car trips in a distance bin $d_i$that are changed by mode shift, relocation or job transfer.

Table 10-3 Weight assignment for adaptation options

Adaptation options	**Living in new urban village**	**Mode shift to bike**	**Mode shift to e-bike**	**Move closer on one's own**	**Change job**
Risk rating	W_0=0	W_1=1	W_2=2	W_3=3	W_4=4

Cost estimation

The cost estimation for developing projects can be calculated using standard engineering methods from relating handbooks or estimator software. In this research, the comparative cost is sufficient for the strategic analysis, as shown in Figure 5. Basically, the number of people involved in adaptation changes could be regarded as the primary indicator to assess the cost for infrastructure development.

Step 4: Transition

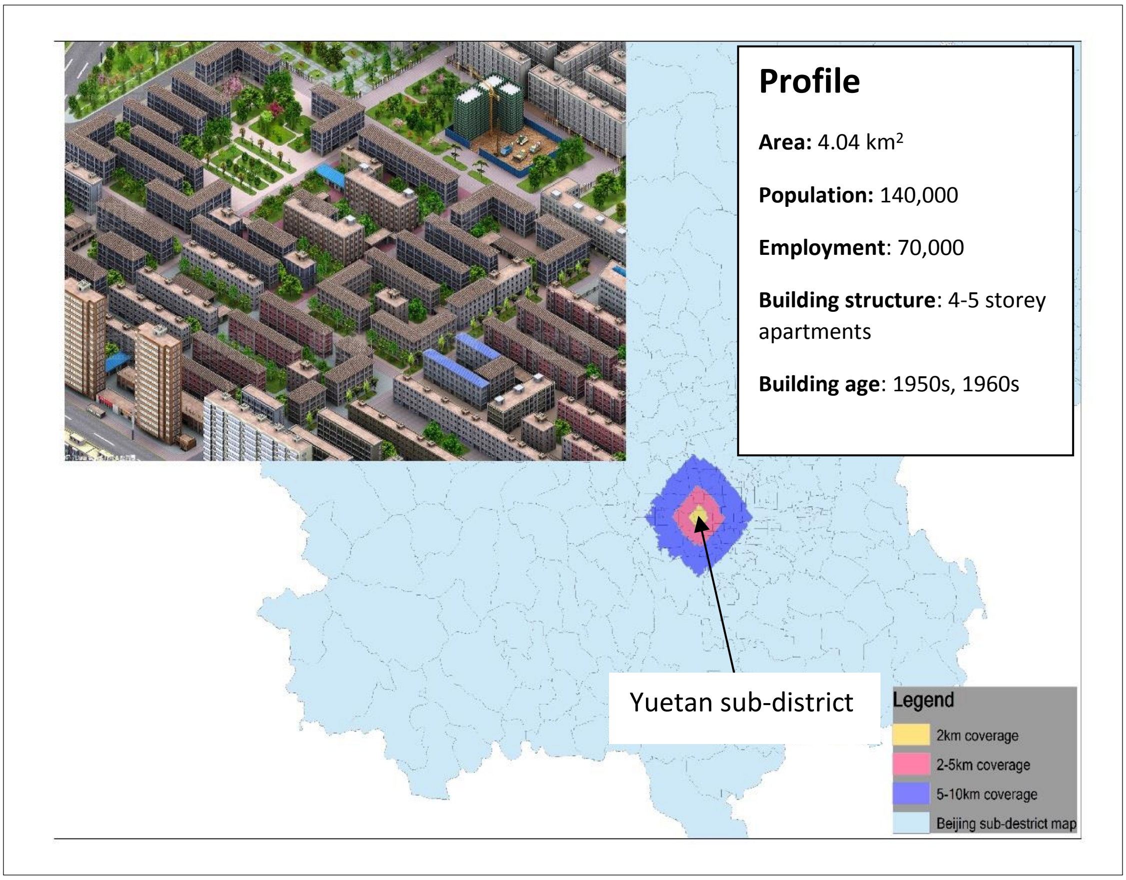
The final step is the change and adaptation of the existing system to reduce and eliminate unsustainability. It is about how to develop and carry out change projects with new ideas, new businesses and new lifestyles around the trigger events. On the basis of strategic analysis results, the computation about some determinants of the change project need to be considered, such as how many people would be involved in the course of redevelopment, how many houses need to be added and how many employment opportunities are required to meet the target.

10.2 Case studies

10.2.1 Shift project 1—Redevelopment for conventional work unit area

10.2.1.1 Status quo of Yuetan

Yuetan sub-district is a conventional work unit area in the city centre of Beijing with a population of 140,000, and employment opportunities of 70,000, where some state organisations and government agencies are concentrated with staff apartments nearby. The building structure in this region is principally characterised by 4 or 5-storey apartments but a small number of high-rise apartment buildings are situated beside the corridor roads (see Figure 10-5). With the decline of the work unit, new employees working in this region are no longer provided staff apartments, forcing them to find affordable housing in suburban areas. As far as commute activities for local residents, based on the calculation from equation (4), it currently shows a relatively higher proportion of short-distance (<5 km) trips with nearly 40% of local residents being able to go to work by walking or bike. The distance-based car trip characteristics in this area can be calculated with local travel mode split data. Due to the absence of a travel survey, the city-level travel split data in Beijing was used to elucidate the methodology.



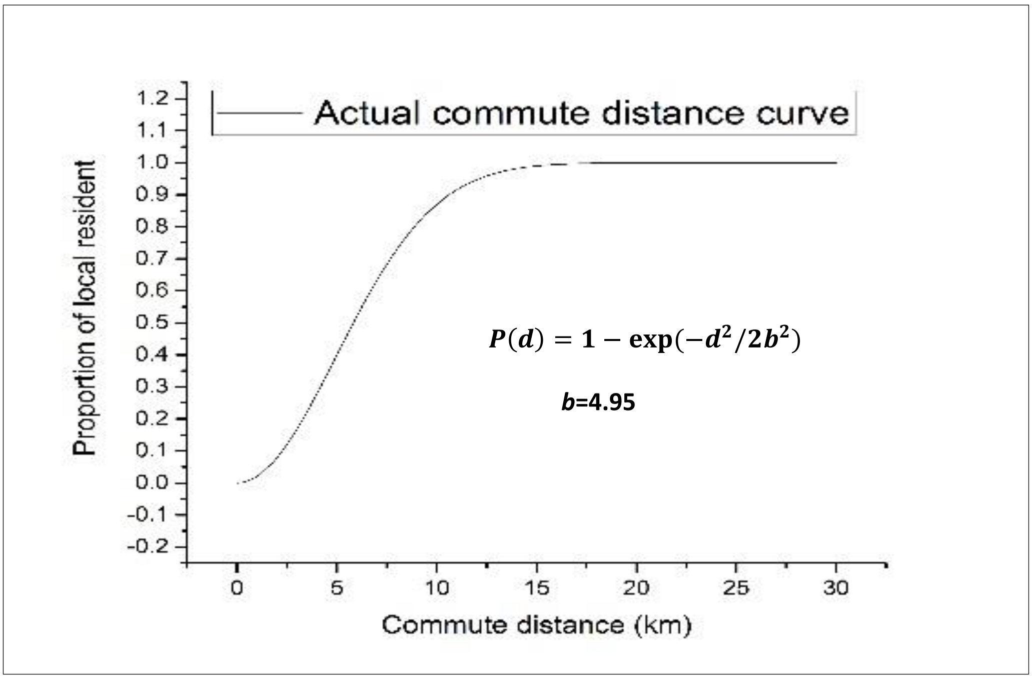


Figure 10-5 Status quo of Yuetan sub-district with 3D map demonstration

10.2.1.2 Develop the possible space

In view of the geographical location of Yuetan, the new urban village design is represented by the work unit provision for a fraction of the employees working in this region. Hence a range of commuter adaptation options under each development scenario are listed in Table 10-4.

Table 10-4 Development options in favour of cycling trips

		Urban form, land use changes		
Transport system changes	*Target: 20% cycle mode share*	Current	Cycle way infrastructure	New urban village (work unit apartment provision)
	Business as usual	Scenario 1: • No change to physical environment • High penetration of bike	Scenario 2: • Regional cycle way infrastructure along the existing local roads	Scenario 3: • work unit provision for 3% employees working in this region • local pedestrian path and cycle way redevelopment
	Electric bike *promotion*	Scenario 4: • No change to physical environment • High penetration of e-bike	Scenario 5: • High speed e-bike way infrastructure • High penetration of e-bike	Scenario 6: • work unit provision for 3% employees working in this region • short length cycle way improvement within local region

10.2.1.3 Develop the feasible space

The possibility of achieving the specified target at 20% cycle mode share under the six development plans were calculated respectively as shown in Table 10-5. All changed car trips follow the hypothesised rules as defined in Section 10.1: Mode shift first, then Distance shift consisting of moving to the work unit, finding a closer residence and changing jobs, until the specified target is achieved. The required individual adaptation options for each development vision are illustrated in Table 10-6 with the necessary behaviour changes involved being checked.

Table 10-5 Possibility of achieving the increased cycle mode share target in different development scenarios

Cycle mode target	**Possibility of achieving the target in different development scenarios**					
	Scenario 1	**Scenario 2**	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***
20.0%	0	19.72%	92.03%	74.69%	90.78%	93.41%

Table 10-6 Adaptation options required to achieve the target (ticked with 'V'')

		Urban form, land use changes		
Transport system changes	*Target: 20% cycle mode share*	Current	Cycle way infrastructure	New urban village
	Business as usual	Scenario 1: • Mode shift in short distance(<5km) **V** • Mode shift in long distance(>5km) **V** • Voluntary move **V** • Change job **V**	Scenario 2: • Mode shift in short distance(<5km) **V** • Mode shift in long distance(>5km) **V** • Voluntary move **V** • Change job **V**	Scenario 3: • Move to new urban village **V** • Mode shift in short distance(<5km) **V** • Mode shift in long distance(>5km) • Voluntary move • Change job

	Electric bike *promotion*	Scenario 4: • Mode shift in short distance(<5km) √ • Mode shift in long distance(>5km) √ • Voluntary move √ • Change job √ **Risk=7849**	Scenario 5: • Mode shift in short distance(<5km) √ • Mode shift in long distance(>5km) √ • Voluntary move • Change job Risk= 7678	Scenario 6: • Move to new urban village √ • Mode shift in short distance(<5km) √ • Mode shift in long distance(>5km) • Voluntary move • Change job

10.2.1.4 Develop the opportunity space

Based on the possibility calculation, impact analysis and cost estimation, the relative merits of the four development scenarios are shown in Table 10-7. It can be seen that the changes in the urban transport system have a significant impact on the potential cycling mode share. If no changes take place in the current urban form and transport system, it is impossible to increase the cycle trips to the desired target by restricting car use only because the long travel distance and lack of cycling infrastructure restrains the adaptation to the cycling mode. Also, the improvement of the cycling environment contributes little to the rise in the cycling mode share. In contrast, the adoption of the electric bike seems to be able to realise the target but with relatively high risks in terms of safety issues and embedded energy consumption. Nevertheless, the electric bike still would be a better alternative for medium-distance car trips if the financial resources are limited. It is highly possible to realise low carbon travel by implementing a work unit design; however, the relative cost for infrastructure and operation is a challenging issue taking account of the high land price in the city centre and the additional financial burden for an enterprise or the government.

Table 10-7 The opportunity space for future development from possibility, risk and cost analysis

Urban form, land use changes				
Transport system changes	*Target: 20% cycle mode share*	Current	Cycle way infrastructure	New urban village
	Business as usual	*Scenario 1* No possibility 0	*Scenario 2* Unlikely $$	*Scenario 3* Likely $$$$
	Electric bike *promotion*	*Scenario 4* Possible $	*Scenario 5* Likely $$$	*Scenario 6* Likely $$$$

10.2.1.5 Transition project

As seen from the results of the strategic analysis for Yuetan Sub-district, the new urban village reflects a good combination of sustainable elements except for cost. Also, it presents a petrol-free potential in the long run, and therefore Scenario 3 is proposed as an example to implement the transition project. The calculation shows that a short length cycleway in the local area is enough to meet the target; accordingly, regional cycleway improvement along the existing local roads was proposed as a redevelopment option for local residents. However, for additional employees, there is no more space for building new apartments in the city centre due to the limitation of land resources. Therefore, a redevelopment scheme for part of the old apartments is proposed to accommodate the additional employees. Based on the calculation results (see Table 10-8), it is estimated that simply by adding 5-8 more storeys to 15 existing apartments, the requirement for accommodating additional employees could be satisfied. It would be better to identify which area is the best place for redevelopment if sufficient information and data are available. In our research, 15 apartments were randomly selected as the shift project for achieving the target. For illustrative purpose, the 3D map of the redevelopment area was depicted with the CityEngine tool (see Figure 10-6). It should be noted that the 3D maps are simply diagrams of the Yuetan sub-district with a number of buildings lacking owing to the limitation of data availability.

Table 10-8 The results of calculations for the new urban village scenario

Additional employees required to live in Yuetan	**Required cycle way infrastructure for local residents**	**Required accommodation for added employees**
70000*0.03=2100	66 km regional cycleway improvement along the existing local roads	Redevelopment for 15 apartments by adding 5-8 more storeys

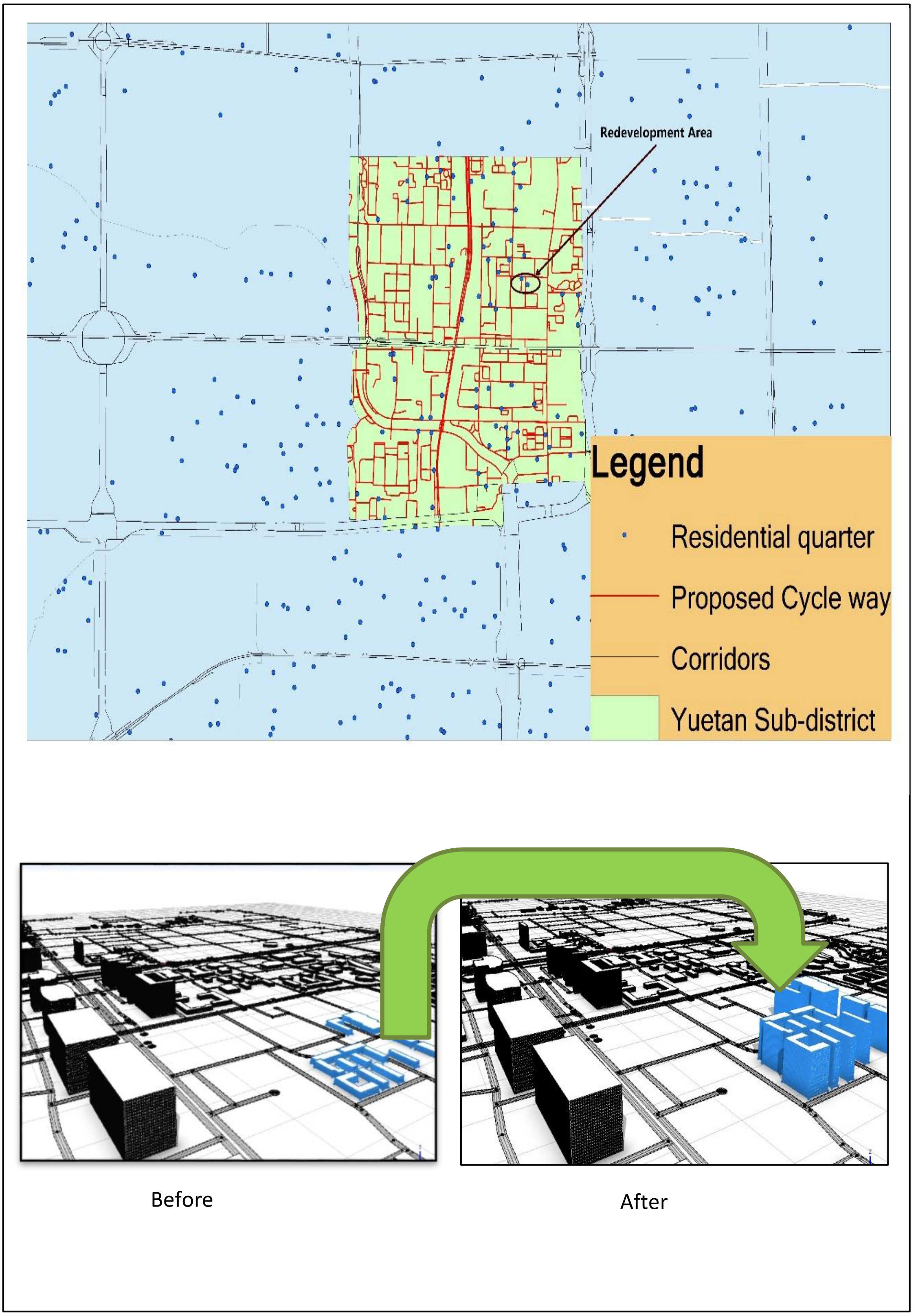


Figure 10-6 The map of the redevelopment scheme with regional cycleway improvements and added storeys for the 15 selected apartments

10.2.2 Shift project 2—Redevelopment scheme for Beijing suburb

10.2.2.1 Status quo of Huilongguan

Huilongguan sub-district (see Figure 10-7) is a typical residential area of Beijing built around 2000-2005, with a population of nearly 330,000 and only 18,000 employment opportunities. The building structure of apartments in this area is represented by a mixed density residence pattern. The parameter of cumulative distance distribution for Huilongguan is b=11.05. According to the travel survey by Qiang and Xiaolin (2007), the proportion of residents in Huilongguan who work within 10 km is around 37%. The corresponding calculation based on the developed commute distance distribution model is as follows:

$$P(10)=1-\exp(-10^2/(2*11.05*11.05))=0.338=33.8\%$$

The derived outcome is almost equal to the observed result; therefore, the developed commute model can be used as a mathematical tool to estimate the commuting distance distribution of Huilongguan area.

It is obvious that this area presents a high jobs-housing imbalance; thus a new high tech business scenario is proposed to add more employment opportunities, which comprise 20% of employment facilities originally located more than 5 km away from Huilongguan (see Figure 10-8). Meanwhile some apartments nearby need to be redeveloped to accommodate the shifted residents who previously lived in the business area.

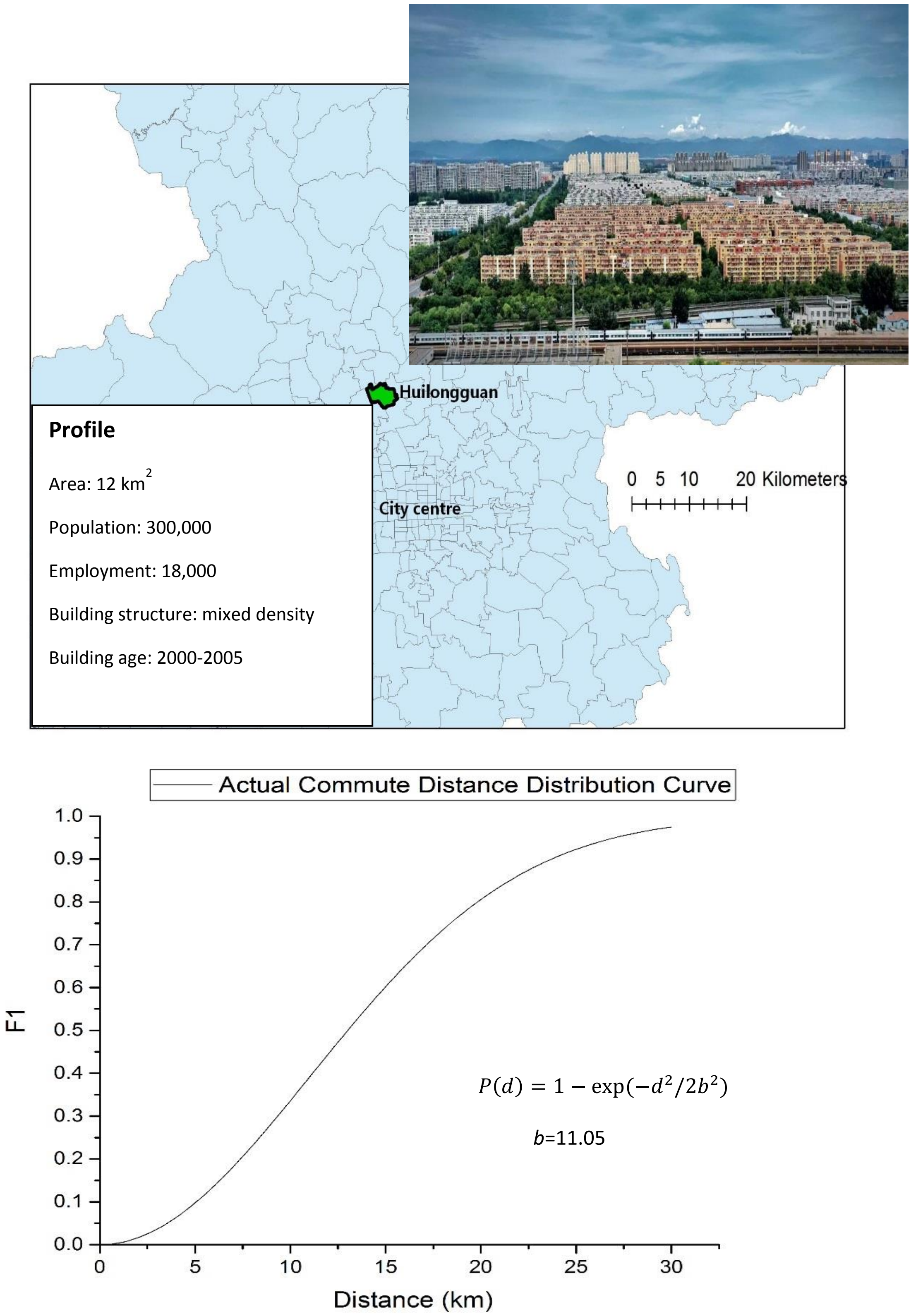


Figure 10-7 Status quo of Huilong sub-district with birds eye view map

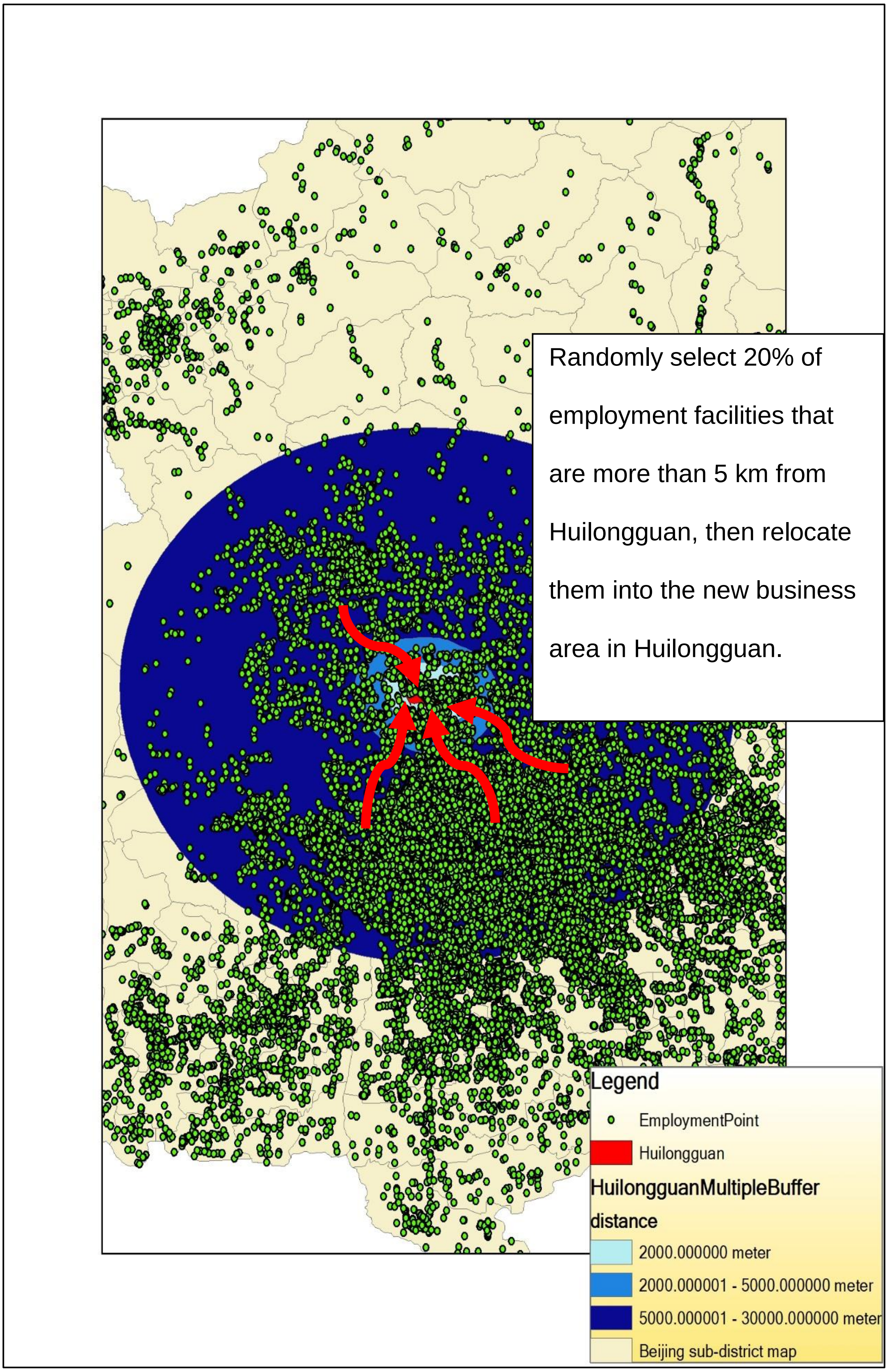


Figure 10-8 Employment facilities migration from the city centre to Huilongguan

10.2.2.2 Develop the possible space

For the residential area with high jobs-housing imbalance, the new urban village is represented by creating more employment opportunities, say a high technology business in this area. The possible space for this area was designed as shown in Table 10-9.

Table 10-9 Development options in favour of cycling trips

		Urban form, land use changes		
Transport system changes	*Target: 20% cycle mode share*	Current	Cycle way infrastructure	New urban village (a new high technology business development)
	Business as usual	Scenario 1: • No change to physical environment • High penetration of bike	Scenario 2: • Regional cycleway infrastructure along the existing local roads	Scenario 3: • A small area of apartments replaced by a number of office buildings • Redevelop some apartments nearby by adding more storeys
	Electric bike *promotion*	Scenario 4: • No change to physical environment • High penetration of e-bike	Scenario 5: • High speed e-bike way infrastructure • High penetration of e-bike	Scenario 6: • A small area of apartments was replaced by a number of office buildings • Redevelop some apartments nearby by adding more storeys • Cycle way network

10.2.2.3 Develop the feasible space

The possibility of achieving the specified target at 20% cycle mode share under the six development plans were calculated respectively, as shown in Table 10-10. All changed car trips follow the hypothesised rules, as defined in Section 10.1: Mode shift first, then Distance shift consisting of moving to the work unit, finding a closer residence and changing jobs, until the specified target is achieved. The required individual adaptation options for each development vision are illustrated in Table 10-11, with the necessary behaviour changes being checked.

Table 10-10 Possibility of achieving the increased cycle mode share target in different development scenarios

Cycle mode target	**Possibility of achieving the target in different development scenarios**					
	Scenario 1	**Scenario 2**	***Scenario 3***	***Scenario 4***	***Scenario 5***	***Scenario 6***
20.0%	0	0 Risk=36579	92.37% Risk=33078	82.17% Risk=32355	91.34% Risk=30509	93.41%

Table 10-11 Adaptation options required to achieve the target (ticked with "√")

<table>
<tr><td colspan="5">Urban form, land use changes</td></tr>
<tr><td rowspan="2">Transport system changes</td><td>Target: 20% cycle mode share</td><td>Current</td><td>Cycle way infrastructure</td><td>New urban village</td></tr>
<tr><td>Business as usual</td><td>Scenario 1:
• Mode shift in short distance(<5km) √
• Mode shift in long distance(>5km) √
• Voluntary move √
• Change job √</td><td>Scenario 2:
• Mode shift in short distance(<5km) √
• Mode shift in long distance(>5km) √
• Voluntary move √
• Change job √</td><td>Scenario 3:
• Work in the newly developed business √
• Mode shift in short distance(<5km) √</td></tr>
</table>

				• Mode shift in long distance(>5km) √ • Voluntary move • Change job
	Electric bike *promotion*	Scenario 4: • Mode shift in short distance(<5km) √ • Mode shift in long distance(>5km) √ • Voluntary move √ • Change job √	Scenario 5: • Mode shift in short distance(<5km) √ • Mode shift in long distance(>5km) √ • Voluntary move • Change job	Scenario 6: • Work in the newly developed business√ • Mode shift in short distance(<5km) √ • Mode shift in long distance(>5km) • Voluntary move • Change job

10.2.2.4 Develop the opportunity space

Based on the possibility calculation, impact analysis and cost estimation, the relative merits of the four development scenarios are shown in Table 10-12. Similar to the conventional work unit area, given no changes in the current urban form and transport system, it is impossible to increase cycle trips to the desired target by restricting car use only because of the high proportion of long commute distances and the lack of cycling infrastructure. Moreover, it seems impossible to raise local cycling mode share simply by improving the cycling environment as the majority of local residents have to travel more than 5km for work. By contrast, the adoption of the electric bike can extend the capacity of people’s medium-to-long distance trip but with potentially higher safety risks. It is highly possible to realise low carbon travel by building a new business quarter in this area; however, the relative costs for the development of new business is a challenging issue taking into account the moving expenses, infrastructure and operational costs.

Table 10-12 The opportunity space for future development from possibility, risk and cost analysis

		Urban form, land use changes		
Transport system changes	*Target: 20% cycle mode share*	Current	Cycle way infrastructure	New urban village
	Business as usual	*Scenario 1* No possibility 0	*Scenario 2* No possibility $$	*Scenario 3* Likely $$$$$
	Electric bike *promotion*	*Scenario 4* Possible $	*Scenario 5* Likely $$$	*Scenario 6* Likely $$$$$$

10.2.2.5 Transition

As seen from the opportunity space, it seems that the combination of new "urban village" plus 'electric bike promotion' scenario is most likely to achieve the proposed target with lowest risks. Accordingly, the new business development vision is selected to represent a transition project for this area. In view of the land area of Huilongguan at $12km^2$, the average travel radius in Huilongguan is around $\sqrt{12}$ =3.46km. Based on the equation, the proportion of residents who work within 3.46km is:

$$P(3.46)=1-\exp(-3.46^2/(2*11.05*11.05))=0.048=4.8\%$$

Then the current number of residents working in the local area is:

300,000*0.7*0.048=10,080

Assuming that at least 20% of commuters would work in the local area after setting up a new business, then the hypothesised number of residents working in local areas is:

300,000*0.7*0.20=42,000.

So at least 42,000-10,080=31,920 employment opportunities are required to be created in Huilongguan area. Accordingly, it is proposed that a small area of apartments is transformed into office buildings, and 15 neighbouring apartments are redeveloped by adding 20 storeys. Assuming the employment accommodation per floor is 200, the residence accommodation per floor is 100, the required number of different factors for redevelopment was calculated, as shown in Table 10-13. The 3D map for the redevelopment in Huilongguan is illustrated in Figure 10-9.

Table 10-13 The results of the calculation for new urban village scenario

Required employment opportunities in local area	Required office buildings in local area	Required cycle way infrastructure for local residents	Required accommodation for shifted residents
31920	15 10-storey office buildings	212 km regional cycle way improvement along the existing local roads	Redevelopment for 15 apartments nearby by adding 20 storeys

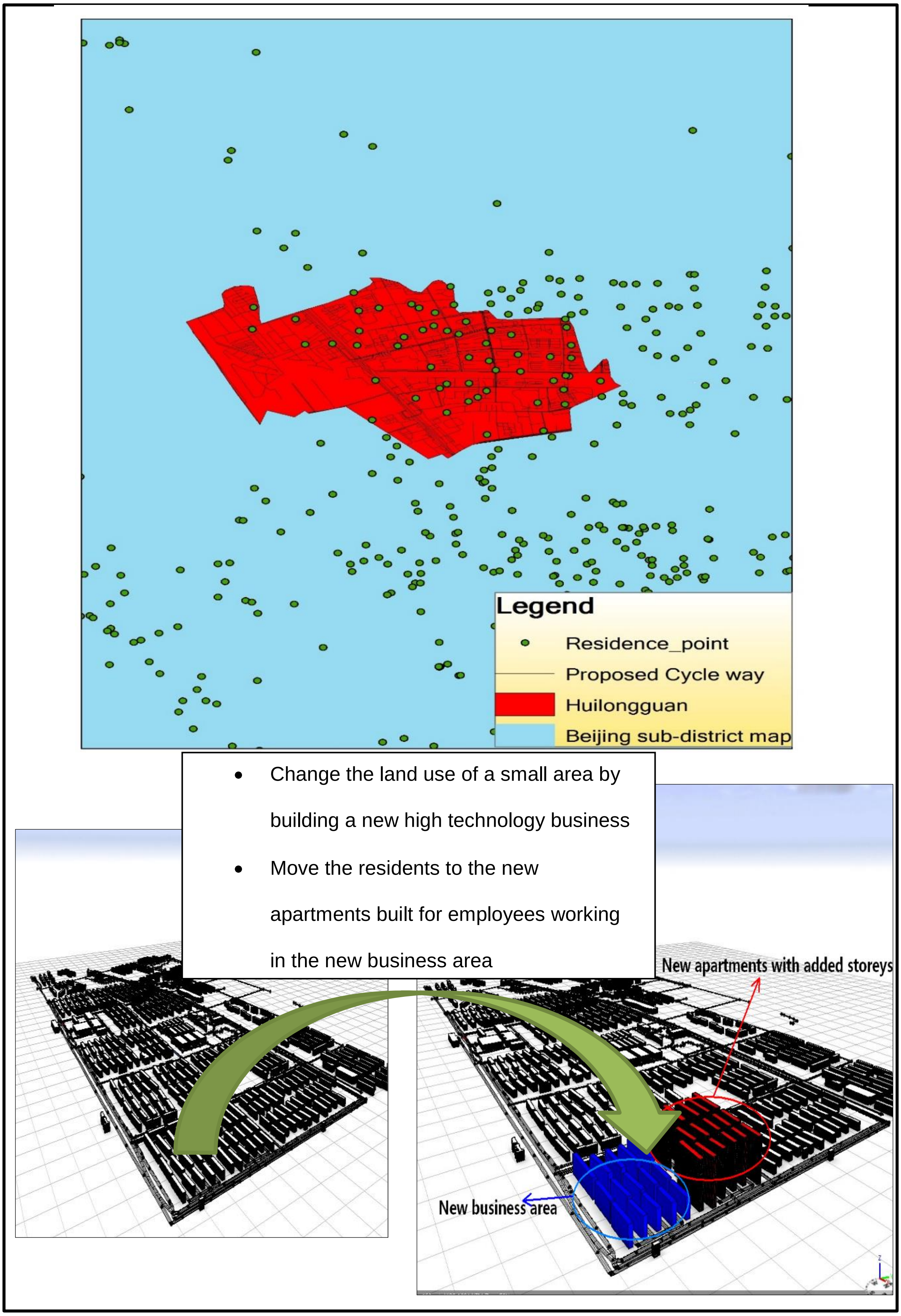


Figure 10-9 The map of the redevelopment scheme with regional cycleway improvements and added storeys for the selected 15 apartments

10.3 Discussion of case study results

The strategic analysis results for two chosen areas in Beijing indicate that the 20% of cycling mode share for commute purposes is a reasonable target that could be achieved by mode shift to electric-bike or building work units in the local area. In both cases, simply by shifting the travel mode from car driving to pedal bicycle contributes little to the increase in cycling mode share even though the local cycling environment is improved. With the decline of conventional work unit form, the average jobs-housing distance of residents living in the city centre has increased owing to the free migration and sprawling built-up area. Nonetheless the vast majority of residents in Yuetan (87%) currently work within 10 km and nearly 40% work within 5 km based on the commute distance distribution model, so the majority of commute trips in this area could be still maintained by riding bikes or electric-bikes even though no petrol bus or private cars are available. In this connection, it is tenable to argue that the conventional work unit area in the city centre is highly adaptable to fossil fuel constraints, and some minor improvements in the local transport networks that are in favour of walking and cycling might make it more adaptable. The suburban area of Beijing presents a high jobs-housing imbalance due to the concentration of employment in the city centre and the dispersal of residents. According to the calculation from the commute distance distribution model, only 10% of residents in Huilongguan work within 5 km and 33% work within 10 km, so the electric-bike might be an alternative means for some medium-distance commuters when the cycling mode share target is not that high; however, it would be more difficult to force more long-distance commuters to ride bikes or electric-bikes when the target is increased to a higher level (say, greater than 40%). Hence it is recommended that a new employment centre be built in this area to offset the high jobs-housing imbalance, or a convenient transit system be intensified in this area to carry more long-distance commuters in the future.

In view of the growing commute distance in Beijing, the classic human-power bicycle does not appear to meet the proposed target, whereas the electric-bike should be a more efficient means to perform short-to-medium distance commute trips. According to BJTRC (2016), nearly 40% of one-way car trips in Beijing are no more than 5 km. If all these car trips could be replaced by bike or electric-bike, traffic congestion and air pollution would be alleviated to some extent. It follows that if the urban form remains unchanged, the electric-bike would be the best alternative way to achieve the low carbon travel target for future sustainable development of Beijing. Apart from that, the work unit design in the local area may be a supplementary means to overcome the jobs-housing imbalance when enough financial support is available.

In summary, it does not seem possible to achieve the target of 20% cycling mode share in Beijing simply by building cycling infrastructure even though the bicycle promotion policy is implemented. When the target is set at a low level of cycling mode share, the electric-bike penetration is a cost-effective way to realise the target but with higher risks in terms of traffic safety and management. The new urban village with work unit design would be the most resilient urban form for sustainable development; however, the cost to implement this development pattern is a challenging issue.

11. Discussion

The essentiality-weighted shopping model and distance-resolved commute model are alternative approaches to characterising the current system for the limitations of the travel survey data availability, with many economic and subjective factors being excluded. Although human travel patterns in practice are heavily influenced by economic levels, psychological characteristics and transport policies, these models provide objective and succinct approaches for low carbon potential exploration and adaptation analysis. Despite the difficulty in obtaining empirical data, this chapter compares the simulated results derived from the shopping models with the observed results derived from mobile phone user data to validate the accuracy of the developed models. Based on the developed essentiality-weighted shopping model, a comparison between before and after establishing a compound shopping mall in a study area was analysed to manifest the energy-saving effect of a diversified shopping development. In an attempt to validate the universality of the commute model, the approaches used in commute activity modelling were also applied to another city, Christchurch in New Zealand with good fitting results. Finally, the improvement on the developed models for future work is discussed.

11.1 Shopping model validation

In reality, due to the absence of detailed travel survey data about shopping trips, and because shopping activities are resilient human behaviour by nature with varying trip distribution and trip frequencies in different timeframes, it is unlikely to validate whether the developed shopping model reflects the real spatial distribution of shopping activities in Beijing. Nevertheless, with the arrival of the big data age, the rise and prevalence of mobile phones enables researchers to access fine-grained information about human mobility on a small scale. Based on the mobile user data, Baidu (a popular search engine equivalent to Google in China) has developed a commercial geography platform called 'Baidu Huiyan' (Smart insight) to provide a range of comparatively reliable data to help property development, decision-making and site location. In order to validate the precision of the developed shopping model in describing the spatial interaction between shoppers and shopping destinations, two types of data from 'Baidu Huiyan' were employed for comparison. One is the shopping heat map in the urban area of Beijing, the other is the customer characteristics for the top ten shopping areas in Beijing.

11.1.1 Shopping heat map comparison

By recording the geographical location of mobile users in different timeframes, the heat map with respect to the human spatial distribution in any region can be interpolated. To this end, a real-time shopping heat map was extracted from the relevant analysis report (Report on shopping centres in Beijing, 2016) by Baidu showing the population flow distribution between 13:00 and 14:00 on a working day in Beijing (see Figure 11-1).

Based on the developed shopping model, the annual average shopping frequency to each shopping cell from each origin cell can be calculated using the equation:

$$f_j = P_i \times F_{shopping} \times \frac{{}^{SE}\!/_{d_{ij}^2}}{\sum {}^{SE}\!/_{d_{ij}^2}}$$

where *S* is the scale of shopping facility *j*, *E* is the essentiality of *j*, d_{ij} is the distance from origin *i* to shopping facility j. $F_{shopping}$ is the surveyed annual shopping frequency of Beijing. P_i is the population of origin *i*.

Then summing the f_j, the overall shopping frequency for each shopping cell throughout the entire city can be obtained:

$$\sum f_j = \sum P_i \times F_{shopping} \times \frac{{}^{SE}\!/_{d_{ij}^2}}{\sum {}^{SE}\!/_{d_{ij}^2}}$$

The interpolated heat map of annual shopping frequency is illustrated in Figure 11-2. Although the two maps are not completely comparable in temporal dimensions (one is real-time, the other one is annual), at first glimpse, the geographical distributions of customer flows in both maps present roughly similar trends with minor differences in hot spots (red areas). It seems plausible that the introduction of essentiality weight into the Huff model could be an approximate alternative to current shopping activities when no relevant travel survey data is available.

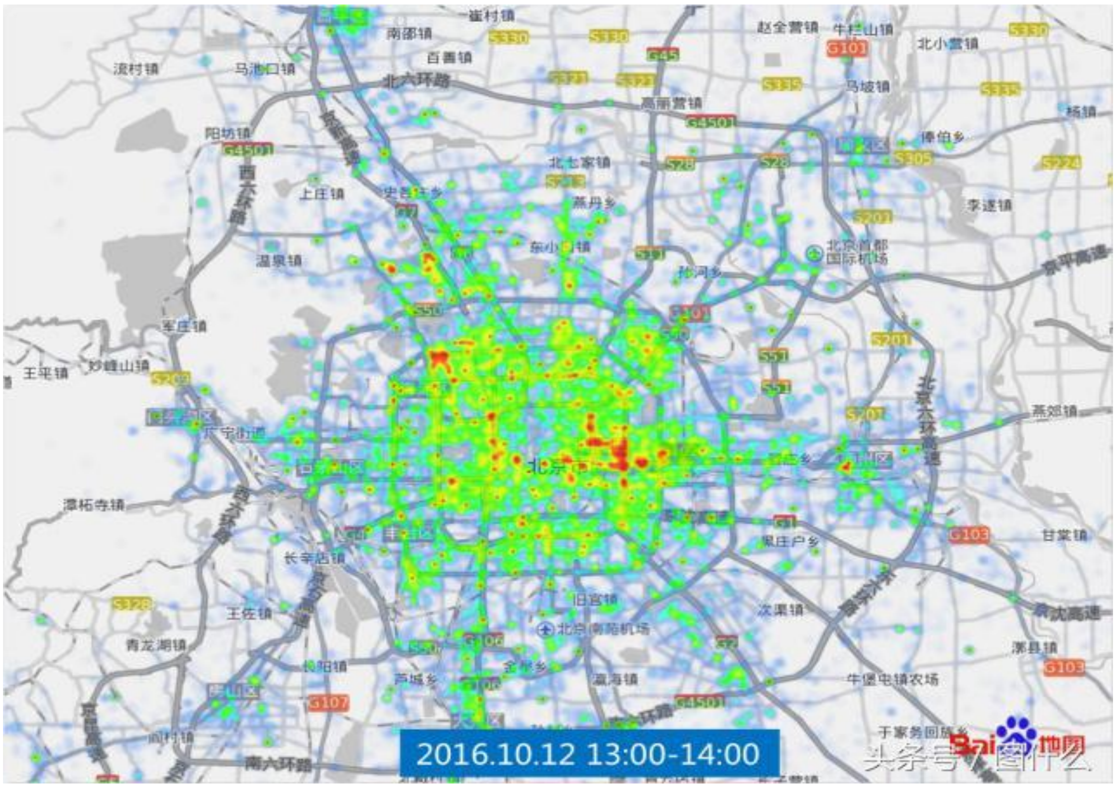


Figure 11-1 The Real-time shopping heat map based on mobile phone trajectory data

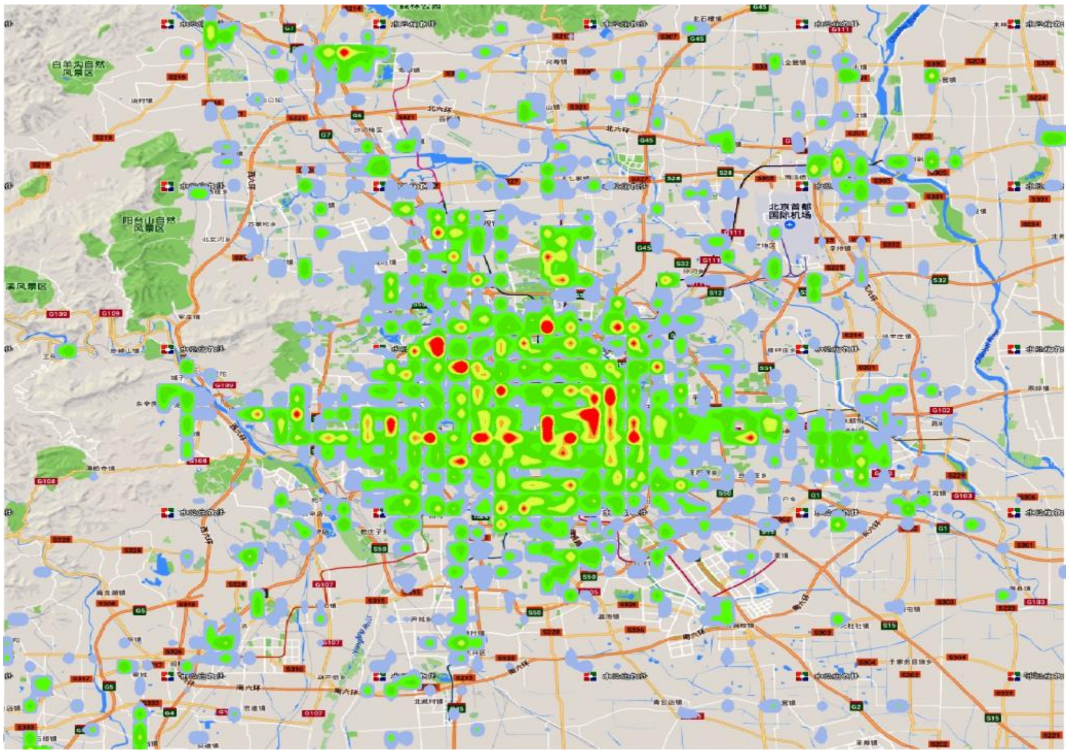


Figure 11-2 Annual average Shopping frequency heat map derived from the essentiality-weighted shopping model

11.1.2 Shopping aggregation comparison

In this report, ten representative shopping areas with highest customer flows were selected from different areas of Beijing to analyse customer characteristics, surrounding facilities and transport (see Figure 11-3). Based on the survey data, the aggregation levels of the ten shopping areas are illustrated in Figure 11-4 and Table 11-1[1], compared with the calculated proportion of shopping trips within 3 km based on the shopping model. It can be seen that seven shopping areas show little differences between the observed values and simulated values (within 20% relative error). However, there are relatively large errors in two traditional shopping areas in

[1] In this report, the proportion of customers who live within 3 km of a shopping centre is defined as the level of aggregation.

the city centre (Xidan Dayuecheng and Kaide Mall) and one newly built shopping area in outer suburban Beijing (Longde).

For these three areas, the simulated results are much bigger than the observed ones. A potential reason may be due to the traditional shopping culture of people to shop in the city centre, making it possible that suburban residents who would theoretically shop in local areas often travel long distances to the city centre for shopping. In addition, some tourists and travellers outside of Beijing are also included in the survey, who are likely to shop in the conventional city centre areas, resulting in a slight decrease of the aggregation level. It is worth mentioning that the customer aggregation around shopping centres in suburban areas is slightly higher than those in the city centre, indicating that the development of large-scale shopping centres in suburban areas could to some extent attract part of local customers who otherwise would travel to the city centre for shopping.

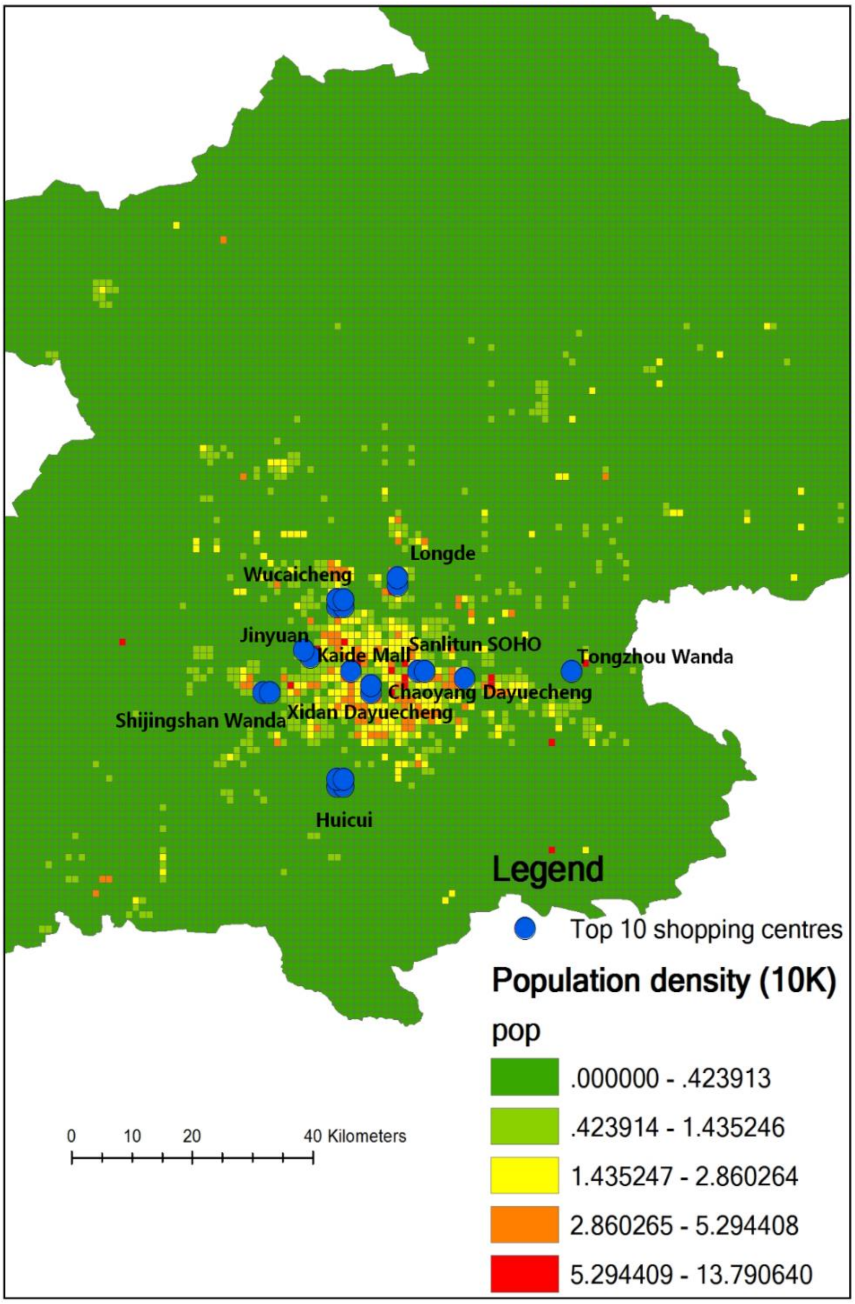


Figure 11-3 The geographical distribution of the top 10 shopping areas

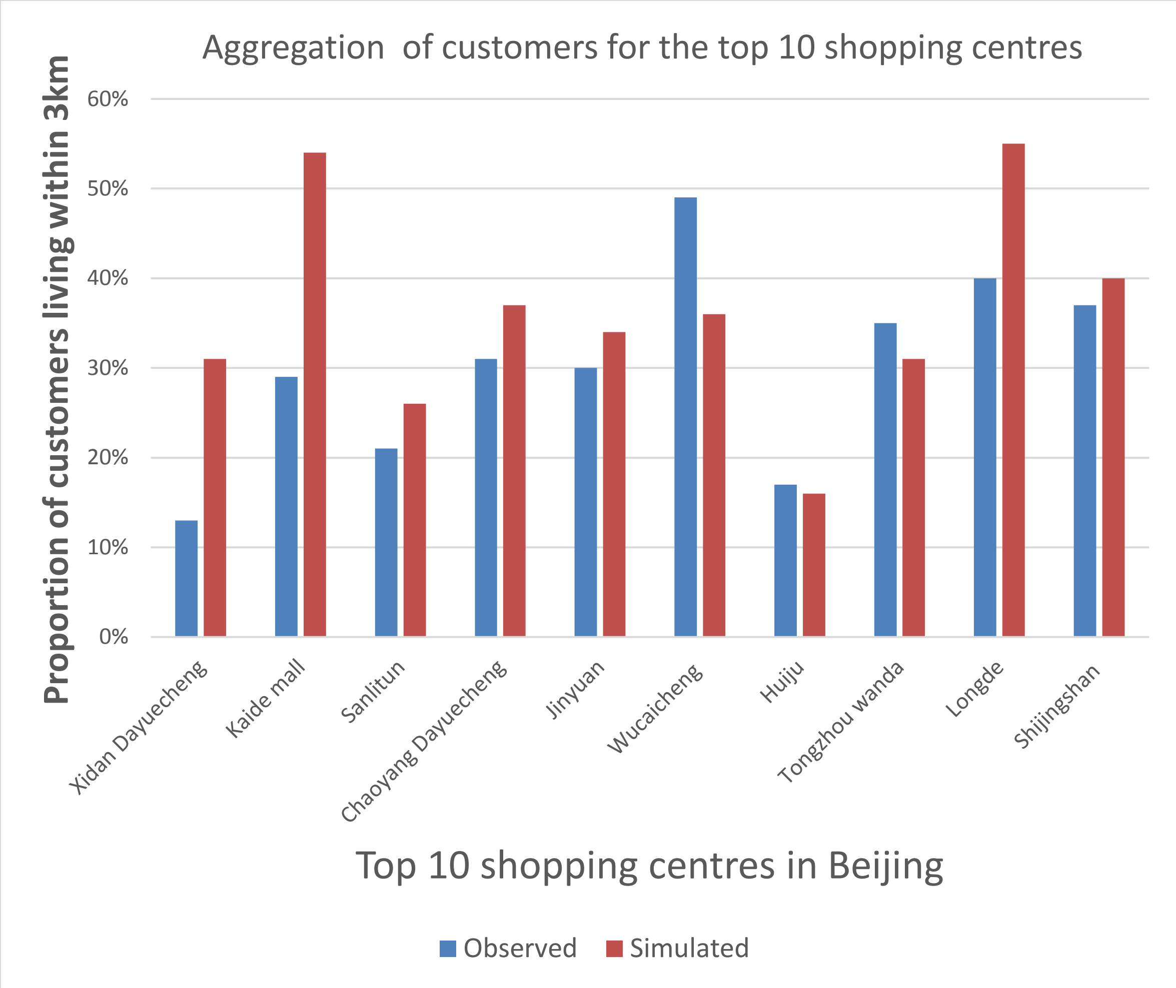


Figure 11-4 Comparison between observed results and simulated results

Table 11-1 Comparison between observed results and simulated results

Name of shopping centre	Location	Observed	Simulated	Relative error
Xidan Dayuecheng ★	City centre	13%	31%	138.46%
Kaide mall ★	City centre	29%	54%	86.21%
Sanlitun	City centre	21%	26%	23.81%
Chaoyang Dayuecheng	City centre	31%	37%	19.35%

Jinyuan	City centre	30%	34%	13.33%
Wucaicheng	suburb	49%	36%	-26.53%
Huiju	Outer suburb	17%	16%	-5.88%
Tongzhou wanda	Outer suburb	35%	31%	-11.43%
Longde ★	Outer suburb	40%	55%	37.50%
Shijingshan	Suburb	37%	40%	8.11%

★： The shopping centres with high relative errors (>30%)

11.2 Energy-saving effect of a shopping redevelopment project

According to the essentiality-weighted shopping model, the scale and the essentiality of the shopping facility, as well as the accessibility to this shopping facility, have a great impact on shoppers' travel patterns. Theoretically an establishment of shopping mall around a residential area would improve local shopping accessibility with higher frequencies, thus reducing local shopping transport energy consumption as a result. In this connection, taking the development of a shopping mall called '**Wucaicheng' (China Resource Dreamport)** as an example, a small transition trial was carried out to compare the shopping transport energy use before and after a shopping mall project development.

'Wucaicheng' shopping mall is a 5-storey compound building consisting of shopping, restaurants, recreation, and sport; the gross floor area is around 200,000 m^2. The area of the Walmart supermarket is 13,000 m^2**.** An external view of Wucaicheng is illustrated in Figure 11-5.

Figure 11-5 The image of 'Wucaicheng' shopping mall

Take a work unit called 'Sinopec Lubricating Oil Qinghe Community' which the 'Wucaicheng' shopping mall is located nearby as the origin zones (Fig 11-6), it can be seen that the shortest OD distance is only 600m. Based on the developed shopping model, the local weighted shopping values in these cells before and after the establishment of the shopping mall were calculated respectively (see Table 11-2). Assuming the distance-based travel mode split in Beijing remains constant, the calculated shopping transport energy use is tabulated in Table 11-2 as well. It appears to be that the large-scale integrated compound design has obvious energy-saving effects on local shopping trips and can promote shopping prosperity as well.

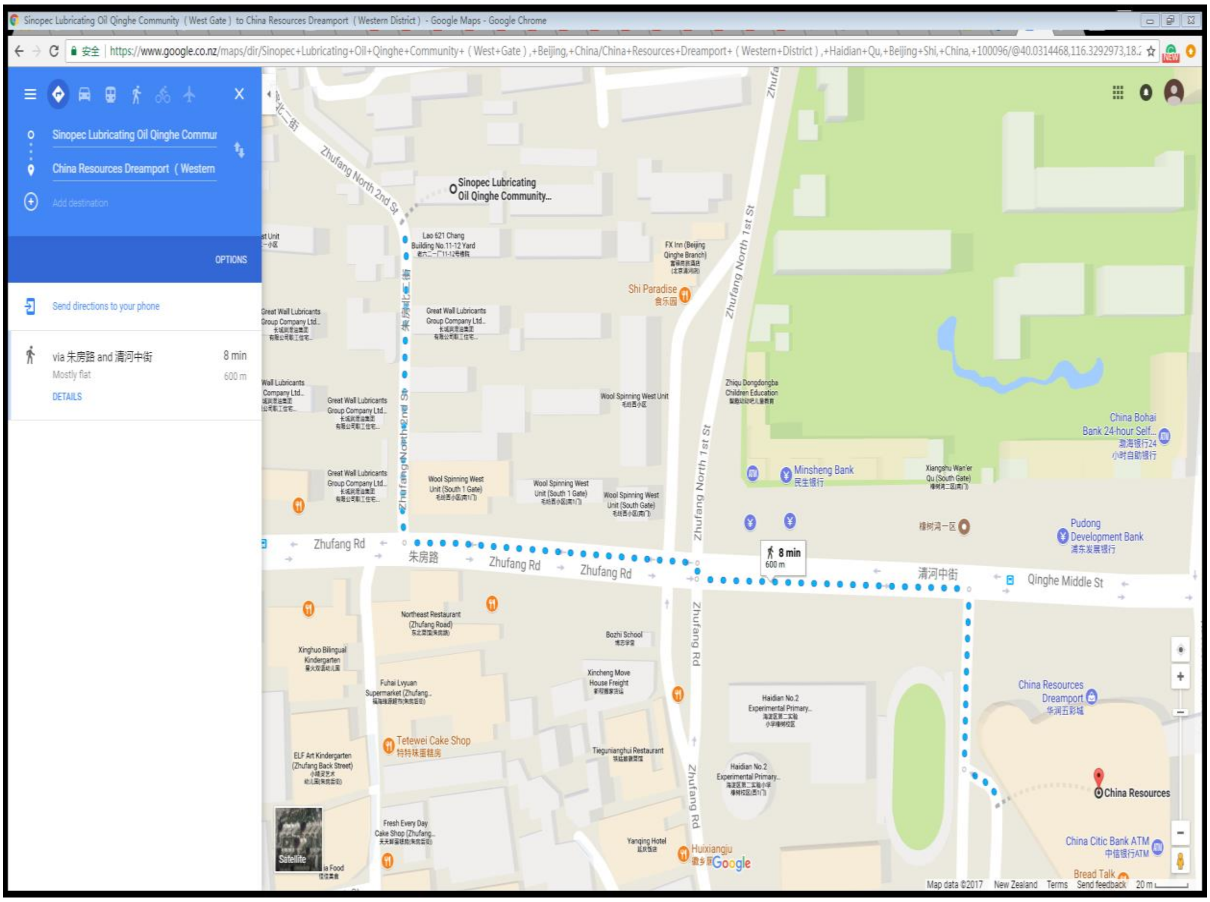


Figure 11-6 The geography of 'Wucaicheng' shopping mall with the minimum travel distance to a work unit

Table 11-2 Comparison of transport energy use and local shopping value

Redevelopment of study area	**Current transport energy use(MJ/person)**	**Local weighted shopping activity value**
Before	781	102077
After	310	146901

11.3 Universality of Commute model

The discovered law about human commuting distance distribution is based on a small sample from Beijing, in order to validate the universality of the developed commute model; the approaches to modelling the commute trip distance distribution of Beijing were applied to several cities in New Zealand. It was found that the commute distance distribution also follows the same law as described in Section 6.2.2. With this model, the low carbon potential can be explored in different distance bins. For a detailed validation of the commute model in New Zealand, please refer to Appendix 2.3.

11.4 Future work

Due to the lack of sufficient information about demographic data and shopping facilities in Beijing, the essentiality-weighted shopping model is simply a probabilistic estimation assuming all shopping activities are home-based one-way trips. In fact, shopping activities are more complicated and more often involved in various trip chains. For example, commuters probably go for shopping around their workplaces after work. Owning a car may change individual’s original shopping choices and building subway stations near shopping centres might attract more customers living further away. Additional variables including socioeconomic factors, transit accessibility and trip chains should be included in future work to make it better reflect the reality. Moreover, in order to improve the accuracy of the developed shopping model, more detailed travel surveys about shoppers behaviours are required to calibrate the parameters in this model.

The distance-resolved commute model in this research is a simulation for cumulative commuting distance distribution without involving directional analysis, with which the concentric circle-shaped distance distribution from an origin zone can be depicted; however, the detailed inter-region trips in different directions and individual commuting OD pairs distribution cannot be derived from this model. A further study will be carried out regarding the quantification of directional distribution of commute trips to unveil the complicated mechanism influencing human mobility.

This model might be used as an 'Apartment finder' or 'Market driver' in Web Map Applications to offer incentives for people to relocate near their workplaces or transit systems. For instance, based on the CUTE model, the most efficient ways for future development plans could be identified. By showing people or stakeholders the candidate residential areas with high active mode accessibility, low energy use, cost-effective potentials and prosperous future, people can score them according to their personal feelings on how living in these areas would match their travel demands for work, shopping, entertainment, education and so forth. Subsequently the area with the highest score would be the market driver for future investment.

12. Conclusions

The urban form and transport system are crucial to participation in human activities. The accessibility of the destination plays a major role in determining human travel patterns. It is undoubted that China will grow into a giant economy stimulating world energy requirements in the next decades. Nonetheless, the risk of peak oil and the upcoming oil demand-supply imbalance would be a serious obstacle for China to overcome. In China, massive urbanisation has led to the immense requirement for motorised travel mode accompanied by severe transport issues and environmental pollution. Although some technical progress makes us more confident about building an environmentally friendly society in the future, the feasibility of renewable energy transport is still far away from reality on account of challenges in its commercialisation and popularisation. Therefore, it is necessary for us to redirect our thoughts from the problem-solving at the bottom end of the transportation systems to the upstream design with ground-breaking ideas. In the face of the predicament between development and sustainability, especially during the process of urbanisation in China, how to design urban form in consideration of energy constraints and comprehensive harmony is a challenging issue for the Chinese government.

Although the work unit is a little obsolete in terms of modern market economy, its compact design and complete function for basic necessities still offers a good foundation for future transition plans. As a production of a centrally-planned economy, the original idea of the work unit was to facilitate employees' living without considering whether or not it was energy-consuming, but interestingly, it has great potential to resist the future risk of an energy crisis and high resilience to possible oil shortages in that its high AMA and all-inclusive services indeed decrease physical travel requirements. The current imitation of the western urban sprawl pattern and automobile-oriented economic growth in China is worth retrospection for future sustainable development. Furthermore, the enhancement of efficient use of public space and maximisation of collective interest should be highlighted during city construction and land conversion in the long run.

The shopping transport analysis provides evidence that the diversified shopping development in the city centre can lead to less shopping transport energy consumption and shorter trip distances for local residents, and the high population density can help to decrease transport energy use as well. The placement of shopping centres in suburban areas may improve local shopping prosperity with lower transport energy use. For megacities like Beijing, high-density development does not necessarily mean a reduction in motorised travel demand if the urban boundary is not effectively contained. With the extension of urban boundaries, the average trip distances would be longer resulting in the high possibility of motorised trips. Accordingly, improving public transportation systems to meet longer distance shopping travel demands is the only energy-efficient way to offset the impact of urban sprawl.

The commute transport analysis reveals that generally the commuting distance in the city centre is shorter than that in the suburban areas; however, with the decline of the work unit, the average commuting distance is gradually increasing with the ongoing urban sprawl trend. The SATS analysis with different development scenarios show that under the target of cycling mode share at 20% in the future, both the ‘electric bike promotion’ option and the ‘new urban village’ option may be regarded as the best opportunities for future development direction but with challenges and risks. When financial support is limited, the adoption of the electric bike might be a good choice to increase cycling trips with favourable infrastructure and efficient management. Although the work unit is now losing its dominance due to the high cost and the deviation from market economy requirement, the new urban village following the work unit design should have more importance. If this pattern is followed it will help to deal with future energy crises in consideration of the perception of localised employment and an all-inclusive urban form in a compact way.

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Appendix Publications and conference papers

1. Journal publications

1.1 Modelling shopping transport energy performance to explore low carbon potentials

Abstract

Using shopping activity as an example, this paper presents a probabilistic model that can be used to estimate shopping transport energy consumption in the absence of empirical data and analyse the potentials of reducing shopping trips by car. Based on the combination of Huff model and Gravity model, some new metrics were developed to quantify the shopping activities. The property of shopping facilities, spatial distribution, travel distance, travel patterns are the key part of model to determine how much transport energy is consumed. With the assistance of GIS system, an international comparison between the two cities in New Zealand and China was conducted using this model to investigate the differences and relevant factors that can affect transport energy use. The results showed that the residential density plays a critical role in reducing shopping transport energy use, the majority of residents living in both cities are adaptable to non-motorized trips in terms of essential shopping activities.

1.Introduction

The reliance on energy in transport and rapidly growing transport CO_2 emissions are a global problem. In New Zealand, transport is the third largest sector of CO_2

equivalent (CO_2-e) greenhouse gas (GHG) emissions, contributing to 18.1% of total emissions in 2012. According to the Ministry for the Environment (2014), a provisional post-2020 target of 30 percent below NZ's 2005 greenhouse gas emissions (GHG) level by 2030 should be met. To mitigate the impacts of Climate Change, it is estimated a 72%-42% reduction in CO_2 emissions is required by 2050. Almost 87% population of New Zealand live in cities, which are the main focus area for transport energy consumption. Accordingly reductions in transport energy consumption can contribute to this mitigation target, projected energy efficiency and vehicle performance improvements could reduce final demand by 40% and transport CO2 emissions by 15%-40% below baseline (IPCC, 2014). It is widely acknowledged that new energy vehicles, mixed land use, transit-oriented transport system and compact urban form can lead to more active mode trips and reduce the heavy dependence on fossil fuel. Although the considerable emphasis on sustainability with more renewable energy and green technologies has been integrated into development plans in many countries, it is believed that the majority of countries are still far from achieving fully sustainable energy systems (The World Energy Council, 2012). Moreover, owing to the peak oil risks and unstable price of petroleum, the need to keep the balance of energy supply-demand becomes more urgent than before. Also China, as a growing economy without sufficient resources, has attached much importance to sustainable development in consideration of energy saving and environmental protection. There is not enough space for transport infrastructure to accommodate a large vehicle fleet. The negative impacts of massive motorization in China such as traffic congestion and air pollution will be even more serious if the dependence on motor vehicle is not effectively controlled (Kenworthy& Hu,2002). In fact, human beings have adaptive capacity to cope with changes in their living environment.

Within an interactive urban transport system, people could adjust their travel behaviour to meet their trip purposes and participate economic activities when land use, transport network or socioeconomic condition is changed. For a car driver, if he or she could access as many as places by alternative travel modes without wasting too much time, he or she would have high adaptive capacity under the condition of energy constraints. For a city or city area, if the majority of activities could be accomplished efficiently without using private cars, its potential in low carbon travel is likely to increase. Living in this area, people's living and trips would not be severely affected given policies such as restrictions on car driving to reduce CO_2 emissions. Based on Huff shopping model(Huff,1963), this paper introduces new measures to quantify shopping activities and develops a comprehensive analytical methodology that simulates urban shopping trips to calculate shopping transport energy use and explore urban adaptive potentials for low carbon shopping trips(i.e. walking and cycling). In this paper, only the spatial factors and travel patterns are considered, the socioeconomic factors are neglected due to the lack of data. All the trips are home based excluding the return-to-home trip legs.

2. Terms and definitions

2.1 Essentiality classification for shopping

It is revealed by surveys of travel behaviour that people rate as 'unnecessary' or 'discretionary' as many as 30% of their trips(Gordon et al.1988;Cevero and RADISCH,1996; Banister et al.,1997). Susan and Shannon(2010) quantified the relative importance of each trip for choosing which trips to take and which activities are preferable. Based on the essentiality theory from Susan, the shopping activity is further refined and divided into three classes:

Essential goods (Dietary needs such as foods and drink): the importance and frequency is highest to human life, which could be accessible in such facilities as grocery store, market, supermarket, department store.

Necessary goods (Clothes, appliance, communication): the importance and frequency is moderate to human life, which could be accessible in supermarket, department store, exclusive store.

Optional goods (upmarket consumption or leisure expense such as flower, pet, antique, jewel): the importance and frequency is relatively low to the majority of people, which could be accessible in department store, shopping mall, exclusive store.

2.2 Huff model

The Huff model(Huff,1963) is a spatial interaction model that calculates gravity-based probabilities of consumers at each origin accessing each shopping facility in the study area. As a gravity model, the Huff model is heavily dependent on impedance such as trip distance or travel time. The definition of the attractiveness of a shopping facility is not generalized, and owing to the lack of available data, only few parameters are used to measure the possibility of consumers patronizing each facility as below:

Scale: The size of shopping facility, ***A.***

For grocery store: the value is set at 20-100 m^2.

For supermarket and market: the value is set at 100-5000 m^2.

For department store and shopping mall: the value is greater than 10000 m^2

Attractor: The frequency to this facility based on essentiality categories, At. For example, the attractor of a grocery store or supermarket or department-store is set as 3, the clothing store is set with 2, the antique store is with 1.

Trip momentum: The trip potential from origin *i* to destination *j*. Based on the gravity model in combination with Huff model, the calculation of trip potential is calculated from the following equation:

$$W_{ij}=(A \times At)/d_{ij}^2$$

(1)

Where d_{ij} is the minimum distance between origin *i* and destination *j*.

Trip probability: The probability from origin *i* to facility *j*, which is normalised as below:

$$P_{ij} = W_{ij}/ \sum W_{ij}$$

(2)

2.3 Shopping value

The measurement to evaluate the level of shopping prosperity in an area is usually divided into a number of dimensions including diversity, quantity, and scale. To simplify the calculation, the conception of shopping value is created to represent the average shopping prosperity in certain area, which is illustrated as below:

$$(SV)_i = \sum_{j=1}^{n} \left(A_j \boldsymbol{At}_j\right)$$

(3)

Where $(SV)_I$ is the overall shopping value in a study area *i*, A_j is the scale of facility *j*, $\boldsymbol{At}_i$ is the essentiality of facility *j*.

2.4 Local weighted shopping activity value

The term of shopping value is a quantitative measure to describe the level of shopping service in each cell. Nevertheless, for each origin *i*, the overall shopping activities it can access within a city is distinctive depending on its location, distance to each shopping facility and the attractiveness of each shopping facility accessible. It is obvious that the shopping activities for people living in the city centre are different from those living in suburb areas. Accordingly the term of 'local weighted shopping activity value' is defined as the function of shopping frequency, shopping value in destination *j* and probability to this destination (see Equation (4)).

$$LSV_i = \sum_{j=1}^{n} \left(f_{shopping} \times SV_j \ \times p_{ij}\right)$$

(4)

Where LSV_i is the overall accessible shopping value in origin *i*, $f_{shopping}$ is the annual shopping frequency in origin *i*, which can be obtained from the travel survey. SV_j is the shopping value in destination *j*, p_{ij} is the probability from origin *i* to destination *j*.

3.Methodology

3.1Spatial analysis for shopping facilities

3.1.1 Mesh grid simplification for study area

To simplify the analysis and reduce the workload, the study area is divided into a fishnet of rectangular cells using GIS tools. Each cell size is set as a 1km×1km square with a centroid (see Fig.1).The centroid is an agent representing the characteristics of origin or destination. For the people living in a cell, it is assumed that they have similar socioeconomic situation. The difference in age, income, personal travel preference are neglected due to the lack of data. All the houses in a cell were abstracted as a point (i.e. the centroid) when running GIS analysis.

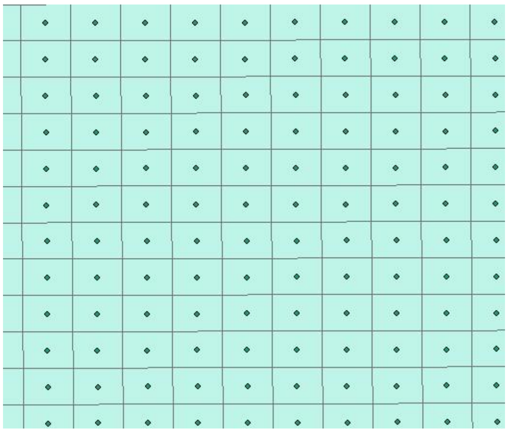


Figure 1. An example of urban grid

3.1.2 Classification and quantification for shopping facilities

All the shopping facilities are classified into different categories and assigned with distinctive values according to the rule of essentiality, then the shopping value in each cell is calculated as the function of number, scale and essentiality of shopping facilities. An example of shopping value distribution in Beijing is presented in figure 2. For a study cell with massive shopping facilities or large scale shopping malls, the shopping value in this cell is assigned with high value(see the red cells in Figure 2). A screenshot of one origin’s shopping trips matrix to each shopping destination is illustrated in table 1. As shown in table1, the coefficient 'Value_shop' describes the level of shopping activities in destination j, 'prob_orig' means the possibility from origin to this destination, 'dist_orig' means the minimum travel distance from origin to this destination.

Transport energy calculation on shopping activities

Given the travel survey data and VKT data in a study area, the local area transport energy consumption could be calculated. However the detailed survey data on shopping activities are difficult to obtain and the individual shopping destinations are extremely random, hence in this paper, it is assumed that for an origin *i*, all the shopping destinations are accessible with certain possibilities. The trip from origin cell *i* to each destination cell *j* is iterated throughout all the study area, then a weighted shopping trip matrix of origin *i* is generated as the shopping trip base data to analyse current shopping transport energy use.

3.2.1 Transport patterns assignment

The detailed travel mode share data based on distance bins is required to do adaptive capability analysis. By doing so, the travel patterns in different distance bins are explicit to explore the possibility of travel mode shift. On the basis of literature view and travel survey data(Guo,2010; MOT,2015), an example of travel mode share matrix of Beijing and Christchurch is listed in tables 2 and 3 respectively.

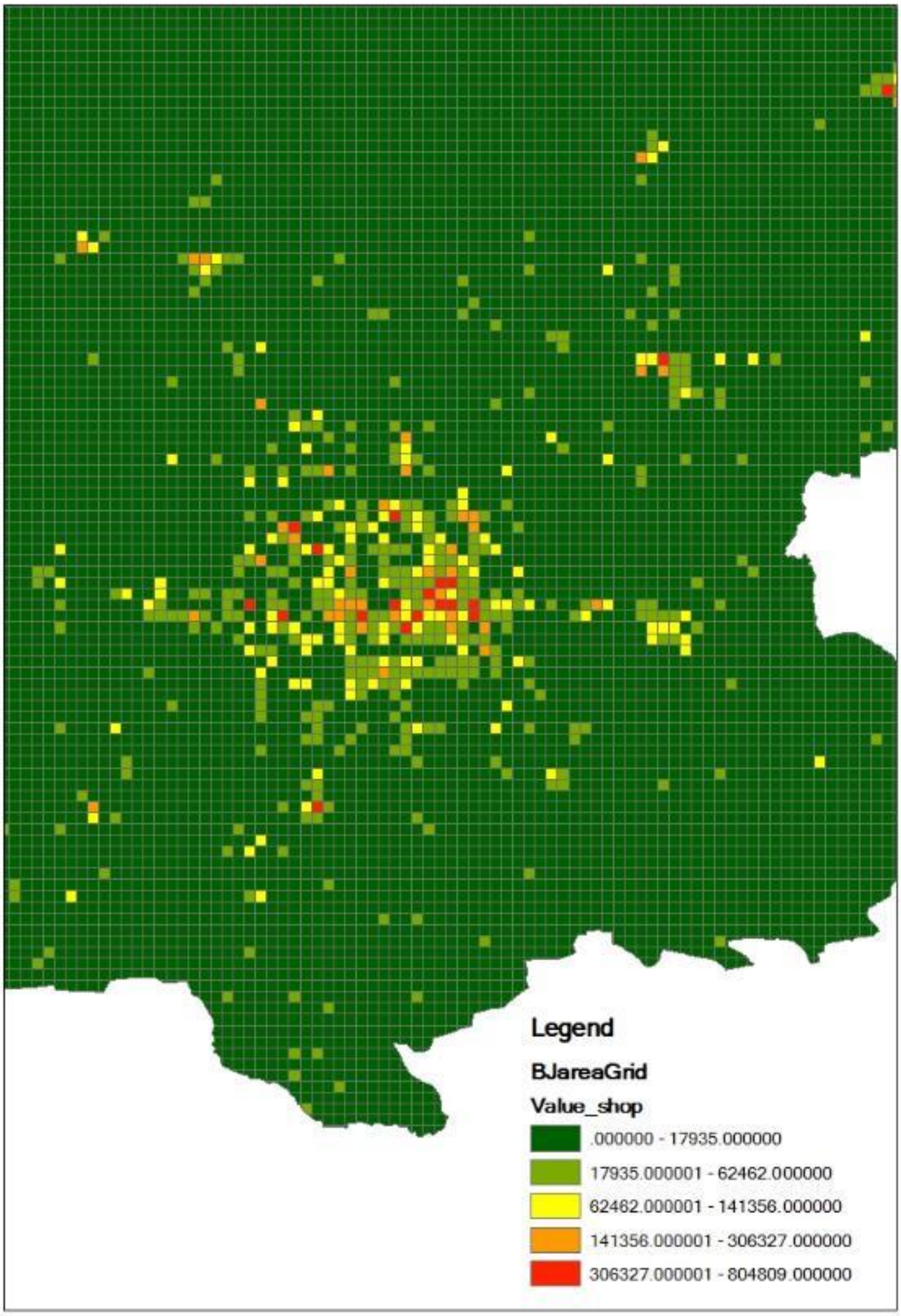


Figure 2. An example of shopping value distribution in Beijing

Table

shopping_centrid

FID	Shape *	Value_shop	prob_orig	dist_orig
0	Point	60	.000020	28062.23935
1	Point	1430	.000494	27519.224042
2	Point	1601	.000573	27030.921267
3	Point	135	.000058	24660.698857
4	Point	41014	.015670	26172.67254
5	Point	461	.000185	25510.661277
6	Point	226	.000103	24019.344488
7	Point	267	.000116	24527.650848
8	Point	240	.000098	25379.957048
9	Point	132	.000050	26329.052992
10	Point	624	.000259	25127.914816
11	Point	235	.000106	24076.829734
12	Point	1555	.000733	23566.918862
13	Point	1286	.000683	22206.235948
14	Point	861	.000485	21560.816478
15	Point	1811	.000944	22405.485116
16	Point	267	.000129	23294.831926
17	Point	727	.000260	27036.85188
18	Point	384	.000145	26367.035187
19	Point	1914	.000735	26109.477626

1 (0 out of 162 Selected)

Table 1. A screenshot of one origin's shopping trip matrix

Trip Mode Split for Shopping (%)	**Distance Bins**(km)					
	*d*1(0-1)	*d*2(1-2)	*d*3(2-3)	*d*4(3-5)	*d*5(5-10)	*d*6(>10)
Walk	90	40	10	0	0	0
Cycle	5	18	20	16	3	0
Bus	3	5	10	10	15	15
Car	2	47	60	74	82	85
Subway	0	0	0	0	0	0

Table 2. Distance-based trip mode split in Christchurch, New Zealand

Trip Mode Split for Shopping (%)	**Distance Bins**(km)					
	*d*1(0-1)	*d*2(1-2)	*d*3(2-3)	*d*4(3-5)	*d*5(5-10)	*d*6(>10)
Walk	89	40	4	0	0	0
Cycle	10	26	30	20	10	0
Bus	0.4	10	30	35	32	35
Car	0.6	10	20	25	35	40
Subway	0	14	16	20	23	25

Table 3. Distance-based trip mode split in Beijing, China

From above tables, it can be seen that the active mode share in Beijing has the same descending trend as Christchurch when the trip distance increases. The car tip share in Christchurch however is relatively higher than that in Beijing mainly because the car ownership ratio is different in these two countries.

3.2.2 Shopping activities simulation

Using GIS tools and Python programming, an activity-based transportation model is developed to simulate people's shopping activities in a year.

Study area input

Demographic data: the population of residents living in a cell (persons/km^2).

Origins: the centroid of each cell is seen as the representative of local dwelling distribution.

Destination: the centroid of each cell is seen as the representative of local shopping facilities distribution with distinctive shopping values.

Transport networks: the travel cost is defined by travel distance. The distance of 3km and 5km is defined as comfort and maximum threshold for cycling travel respectively. Congestion and trip chains are neglected.

Constant input

Modal energy intensity, $\boldsymbol{em_{mode}}$

{'walk': 0; 'bicycle':0; 'bus': 0.37MJ/(person×km); 'subway':0.26MJ/(person×km), 'car':3.64MJ/(person×km)}

Shopping trip frequency $\boldsymbol{f_{shopping}}$. The average annual shopping frequency at the city level can be derived from travel survey data.

Distance-based travel mode share data, $\boldsymbol{T_d}$.

3.2.3 Transport Energy calculation

For an origin *i*, the transport energy consumption for shopping by travel mode is calculated from the following equation:

$$E_i^m = \sum_{j=1}^{n} \left(d_{ij}^m \times em_{mode} \times f_{shopping} \times T_d \times p_{ij} \right)$$

(5)

$$E = \sum_{i=1}^{n} (E_i^m) \text{ /population} \tag{6}$$

Where *E* is the average transport energy use per person in origin *i*, d_{ij}^m is the distance from origin *i* to destination *j*, em_{mode} is the energy intensity of travel mode,

$f_{shoping}$ is the shopping frequency per year, T_d is the distance-based travel mode share.

3.2.4 Adaptive capacity analysis

In this paper, it is assumed that for a short distance trip (less than 3km for walking or 5km for cycling), the fossil fuel transport mode is not necessarily required and could be replaced with non-motorized travel modes like walking and cycling. If the majority of shopping activities could be accomplished by active modes, the low carbon potential in this area would be the highest. In view of the limitation on space, only the adaptive capacity in walking and cycling was considered in this paper. The analysis on public transport adaptive capacity will be presented in the future.

The adaptive capacity for shopping is defined as the local weighted shopping value within walking distance (0-1km) and cycling distance (0-5km). The higher the local shopping value in short distance, the more adaptable to non-motorized trips.

Step 1. Shift all car trips within 1km into walk trips.

Step 2. Shift all car trips between 1km and 5km into cycling trips.

Step 3. Keep the car mode share beyond 5km constant.

Step 4. Recalculate the local weighted shopping activity value of each cell assuming all the car trips within 5km are replaced with walk mode(<=1km) and cycling mode(<=3km or 5km) to see how much shopping value could be realized with 0 transport energy use.

It is not clear that how many shopping facilities would be critical to meet individual commercial requirement, also the question on how much adapted shopping value is satisfactory for consumers is difficult to define. In this paper, the 25 percentile of original local shopping value is used as the evaluation criteria to assess the impact of mode shift on **essential** shopping activities, the 75 percentile of original local shopping value is used as the evaluation criteria to assess the impact of mode shift on **necessary** shopping activities. The ratio of population that can access essential and necessary shopping activities within non-motorized trip distance bins (0-1km,0-3km,0-5km) will be compared between the two cities.

4. Case studies

The method was applied into two cities in China and New Zealand to compare the shopping transport energy consumption and results of mode shifting. Beijing and Christchurch are completely different in terms of urban form, demography, transport systems. One is a megacity with highly mixed land use, high-rise buildings and dense population, the other one is a medium-sized city in a way of dispersal, low-density and separation. The urban area of Beijing is around 1368.32km^2 with 18,590,000 population, the Christchurch urban area is 607.73km^2 with 381,800 residents (Fig.3 and Fig.5). In the aspect of shopping activities, the geographic shopping value in each cell is calculated using Eq.(3) and mapped using GIS(see Fig.4 and Fig.6). From these maps, it can be seen that the average shopping value in Beijing is much higher than Christchurch, the city centre is the important concentration area with extensive shopping activities no matter in Beijing or Christchurch. The hot spot for shopping in Christchurch is more evenly distributed than that in Beijing. Nevertheless there are number of small shopping districts outside the urban area of Beijing city

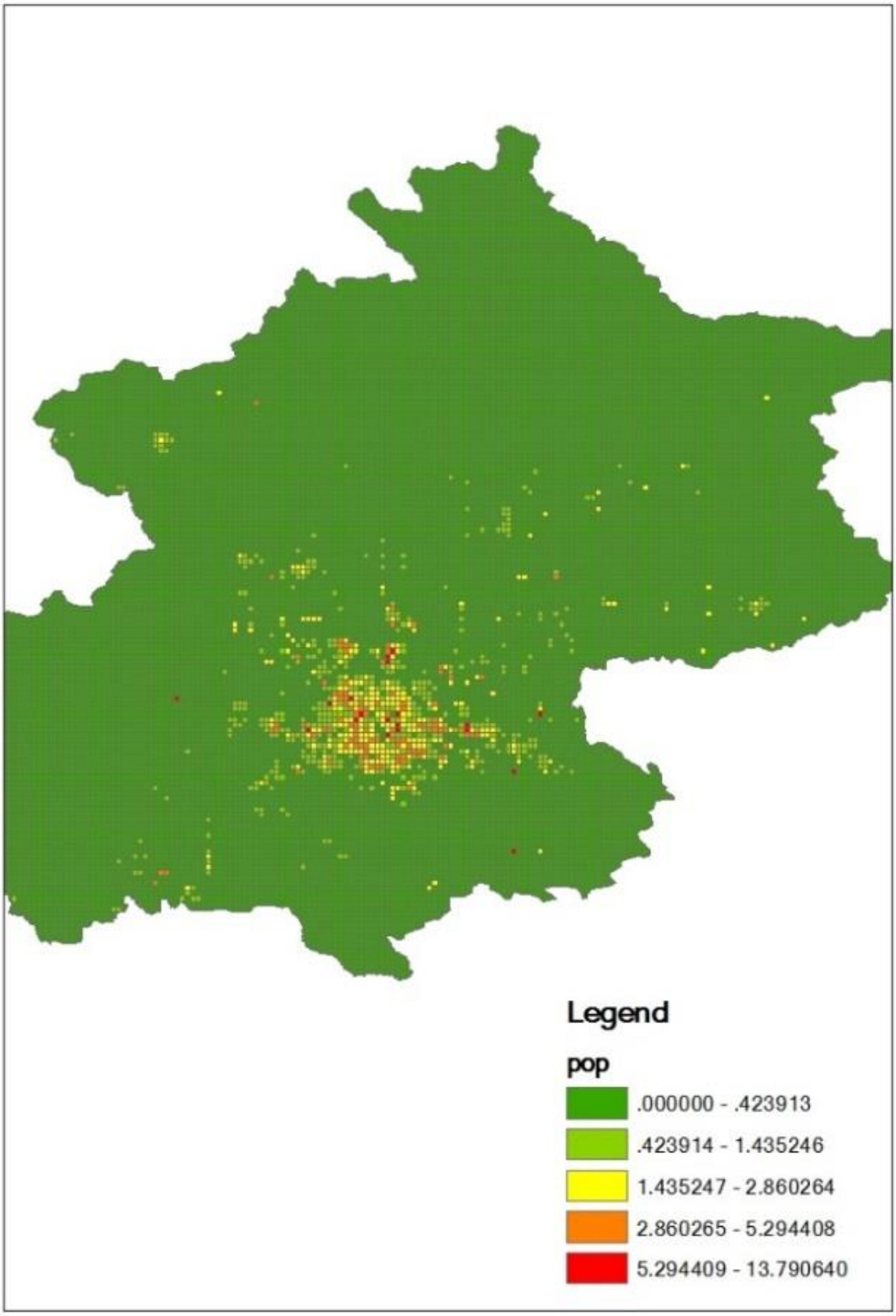


Figure 3. Population density distribution in Beijing

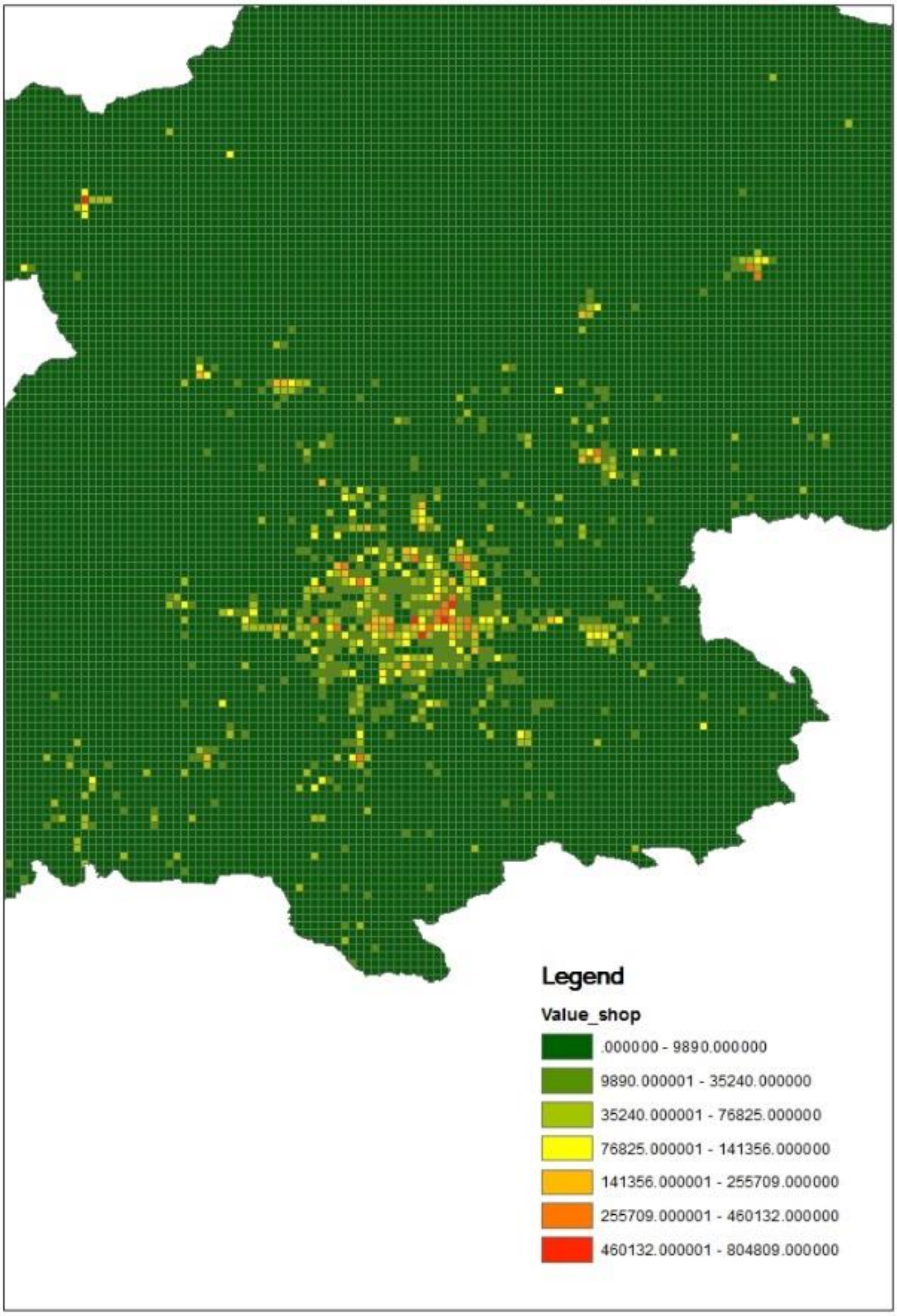


Figure 4. Shopping value distribution in Beijing

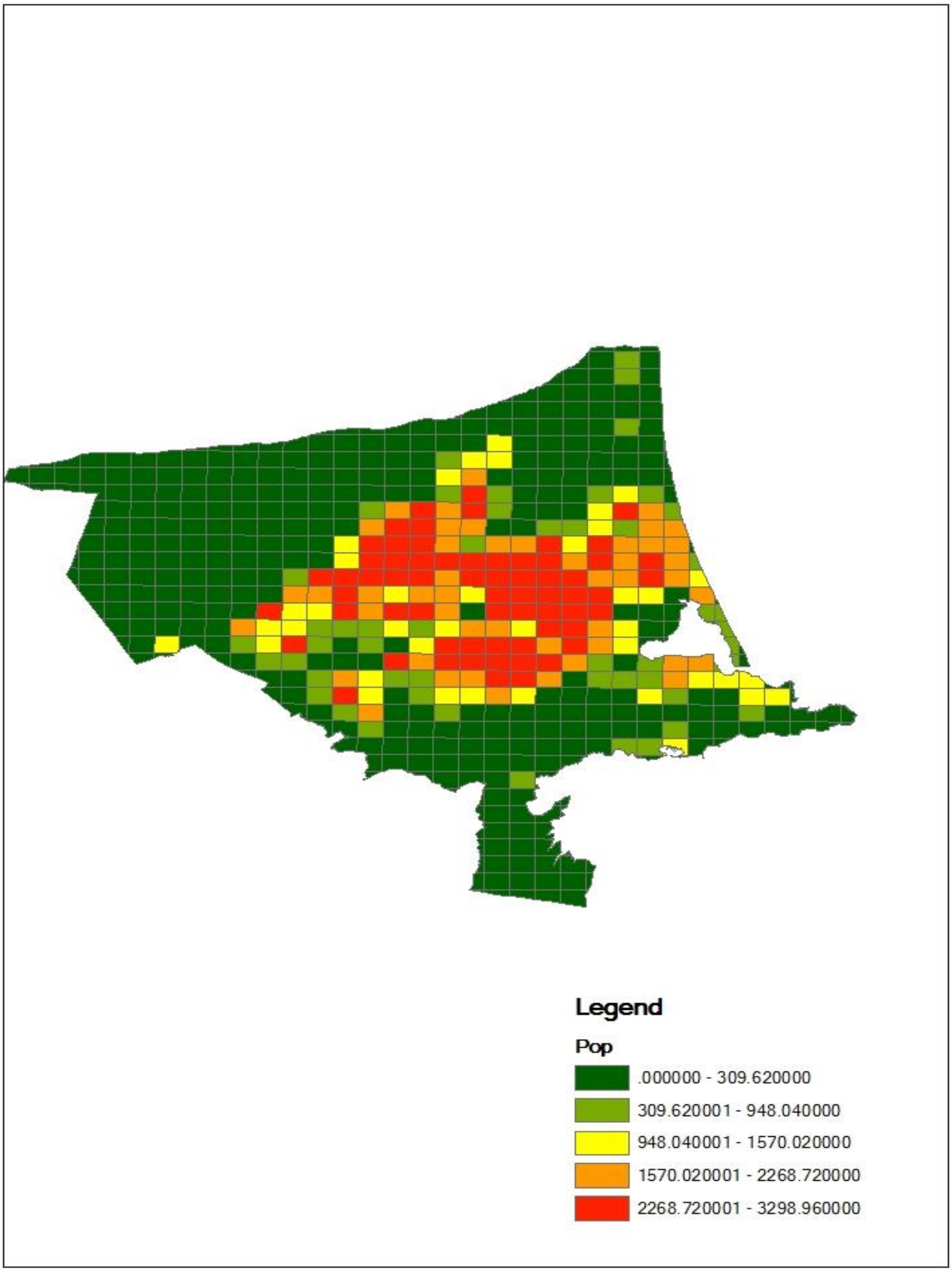
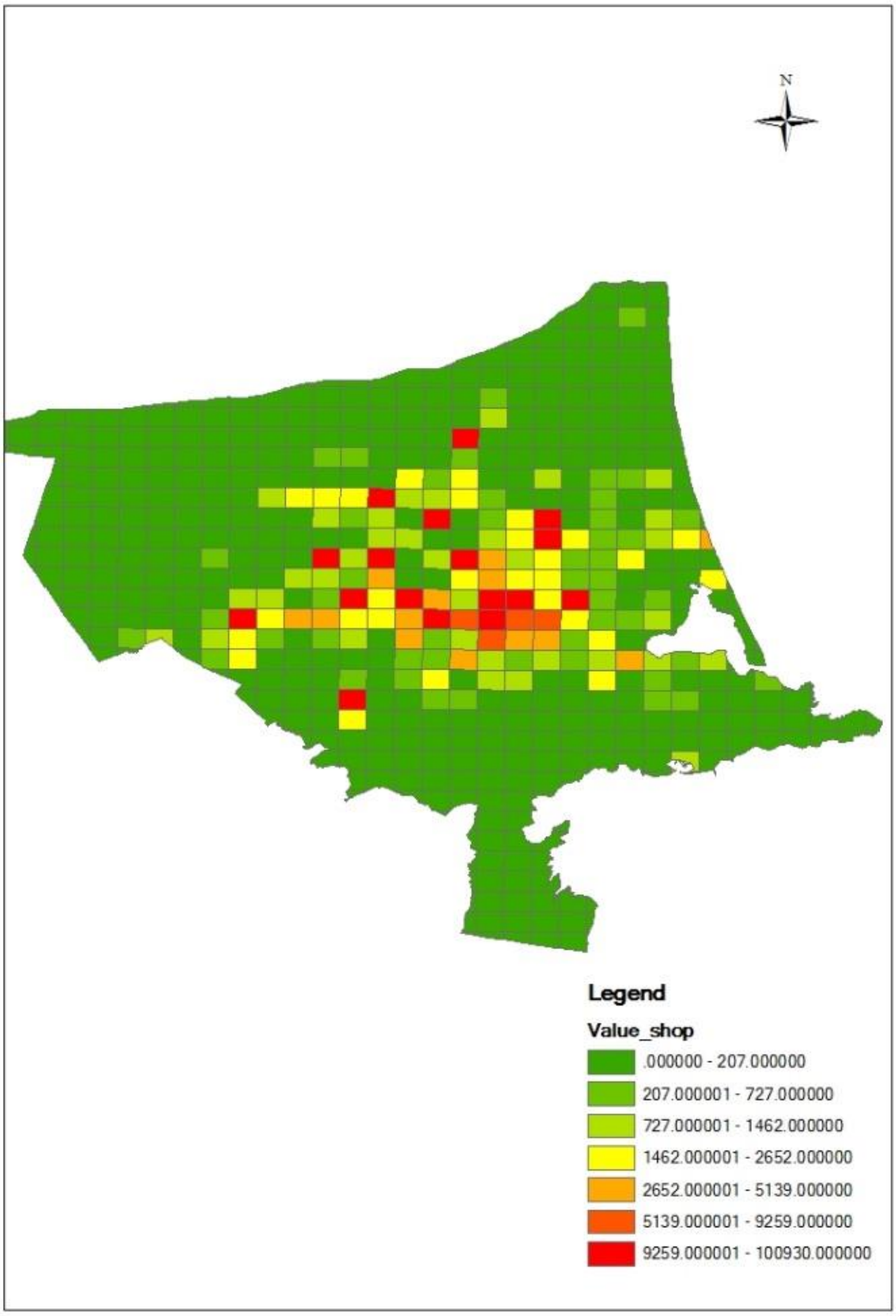


Figure 5. Population density distribution in Christchurch

(Unit: person/km^2)



5.

Figure 6. Shopping value distribution in Christchurch

Discussion and analysis

For each cell, the travel patterns and shopping values in different distance bins were calculated based on trip mode split for shopping. A cell close to the city centre of Beijing (cell A in Figure 7)and another one faraway(cell B in Figure 7) were selected as the example to show how the distance and shopping facility distribution affect trip frequency and shopping activities. Cell A is closer to the high-value shopping districts resulting in higher frequencies and better shopping service available within 5km. For people living in cell B, the motorized travel requirement is generated if they want to access more shopping facilities because of the lower level shopping services within short distance. By analysing the travel patterns in each cell, the adaptive capacity and relating shopping value at micro level could be derived as a close-up observation for analysis.

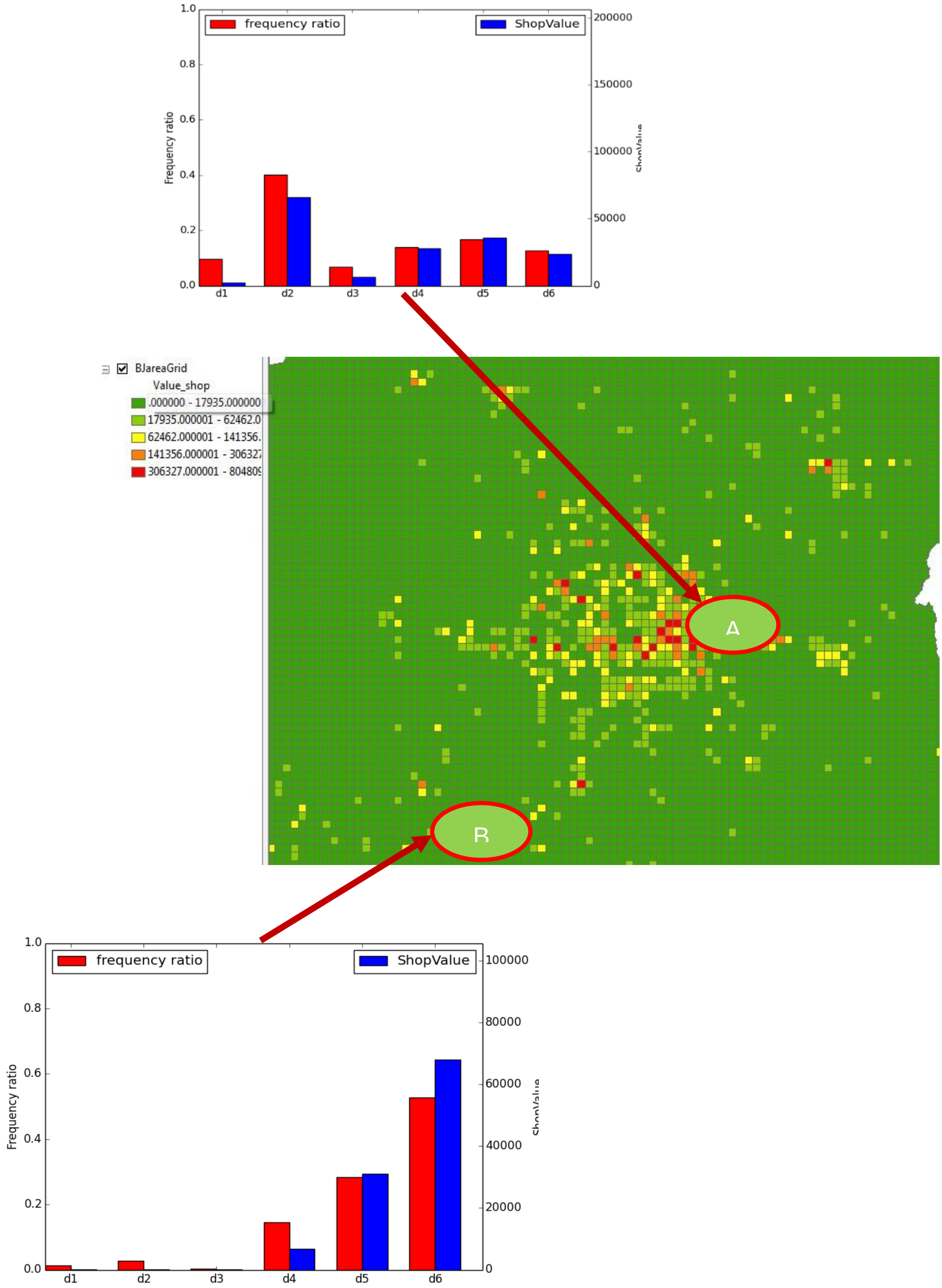


Figure 7. Example of travel patterns in each cell

The calculation of transport energy consumption in each cell was iterated throughout Beijing and Christchurch using Eq.(5) and (6) and mapped by applying the interpolation method in GIS, which is shown in Fig.8 and Fig.9. For both cities, it is similar that the city centre and surrounding areas have the lowest transport consumption because of the higher density of population and higher level of shopping services. In the outskirt of Beijing city, there exists several regions with lower transport energy use due to the long distance to the city centre. Combined with the shopping value map in Beijing, the level of shopping services in these regions are fairly good reducing the travel demand to the city centre. Also in Christchurch city, the southwest area and are of the lowest transport energy use owing to the same reason. Table. 4 is a comparative analysis on transport energy use, Vehicle Kilometres Travelled (VKT) and trip distance between Beijing and Christchurch. It is obvious that the motorized trips of Christchurch are much more than Beijing but the average trip distance is shorter owing to its smaller size of urban area. Therefore it is conceivable that a small-medium city has higher potentials for non-motorized trips than a large city. In particular, the calculated VKT value of Christchurch(1121km) based on this model is almost the same as the data (1170 VKT for shopping) derived from the travel survey by The Ministry of Transport and literature view (NZTA,2006; MOT,2015). Therefore, it might be an alternative measure to estimate the VKT data in a study area if there is no travel survey data available.

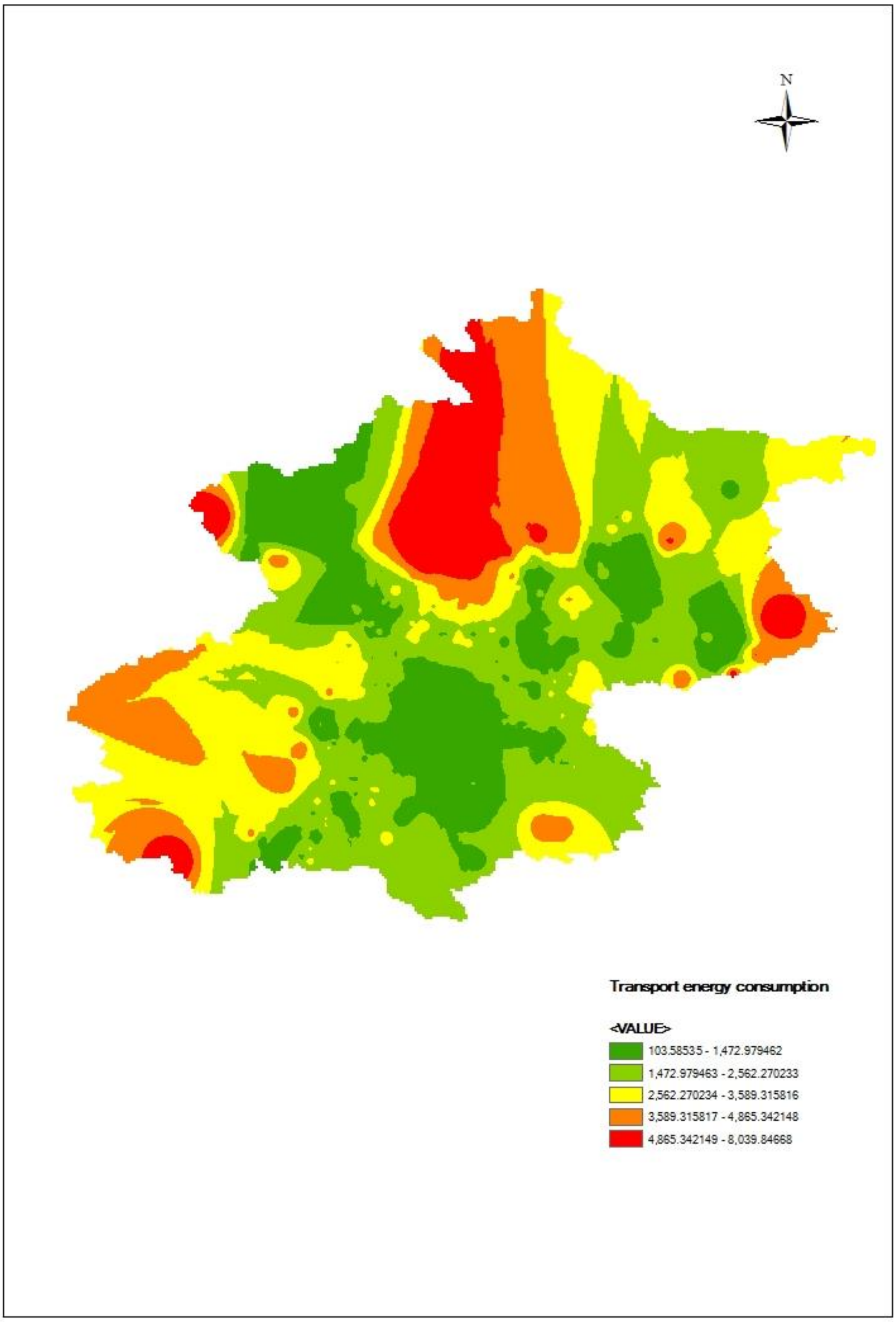


Figure 8. Transport energy consumption distribution map of Beijing

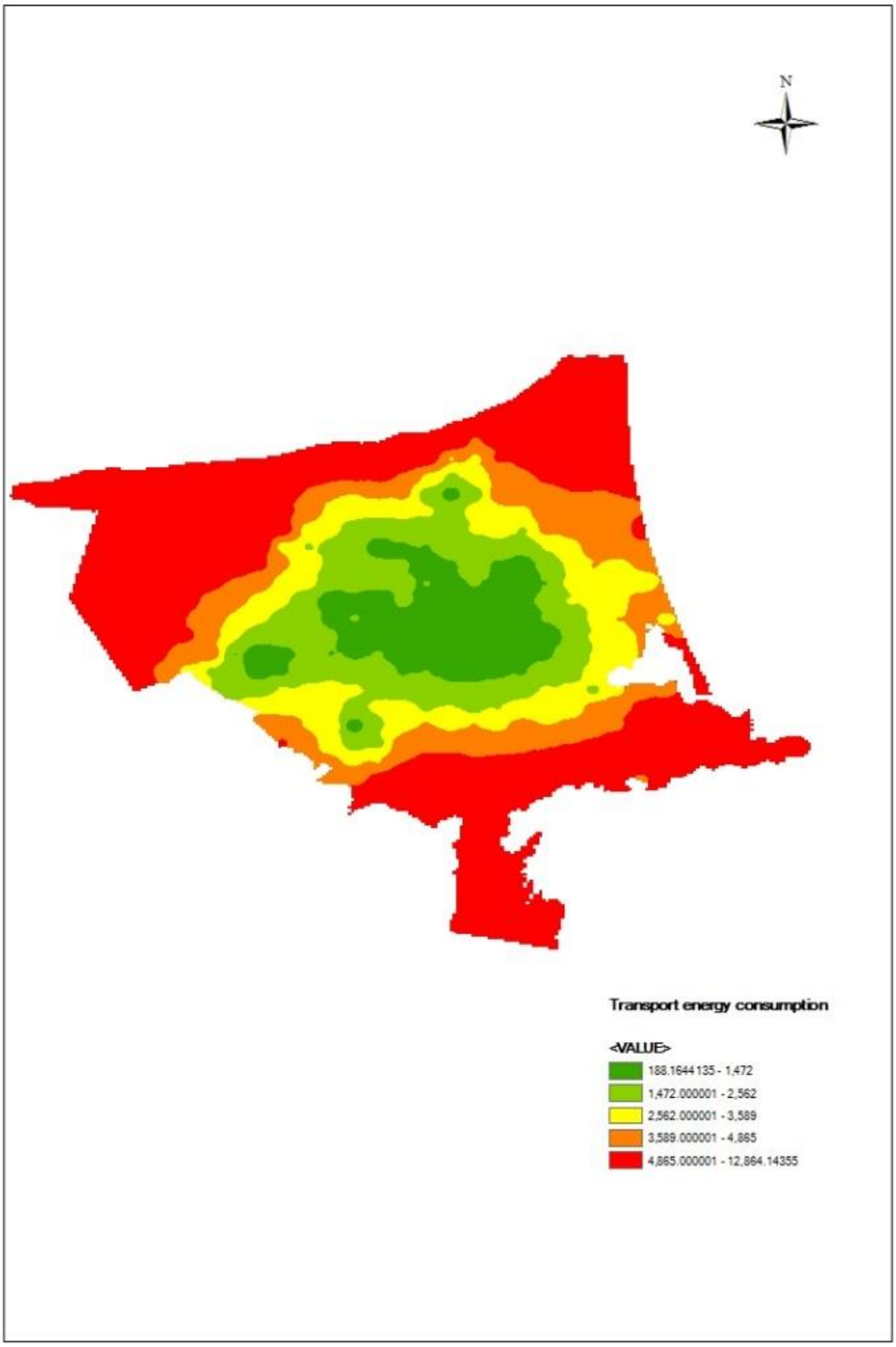


Figure 9. Transport energy consumption distribution map of Christchurch

City	Average transport energy use for shopping(MJ/person)	Average weighted VKT for shopping(km/year)	Average trip distance for shopping(km/day)
Beijing	1286.78	301	11.08
Christchurch	4137.80	1121	7.5

Table 4. Comparison on travel patterns between Beijing and Christchurch

It is generally argued that the carbon emission is negatively related to the population density, which is testified by the transport energy consumption vs. population density analysis in Fig.10 and Fig.11. All the cells in each cities were transformed into scatter chart with a division line and a trend curve highlighted in these two figures. It can be seen that both transport energy consumptions have the similar descending trend as the population density increases. Quite a few of residents in Christchurch consume more than 2000MJ/year for shopping activities, however the majority of Beijing's shoppers consume no more than 4000MJ/year, which mainly results from the differences in car ownership ratio and travel mode share.

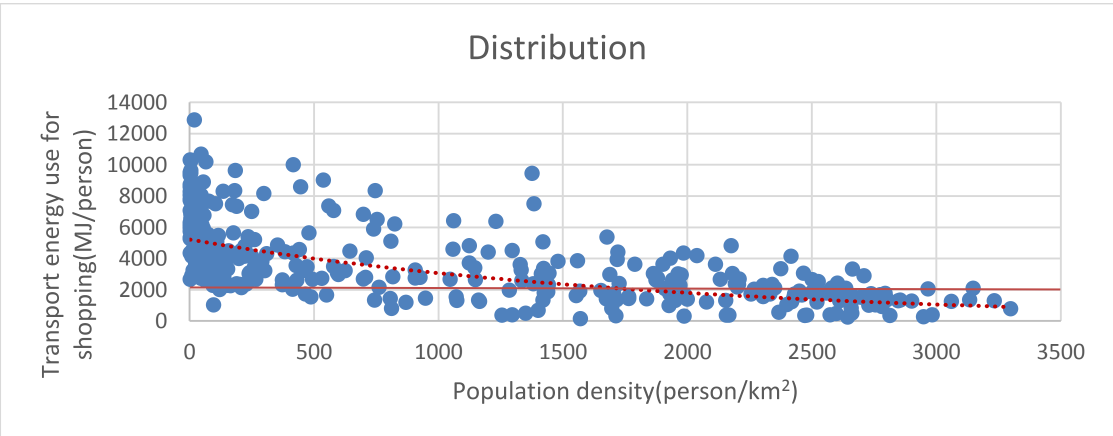


Figure 10. Correlation between transport energy use and population density in Christchurch

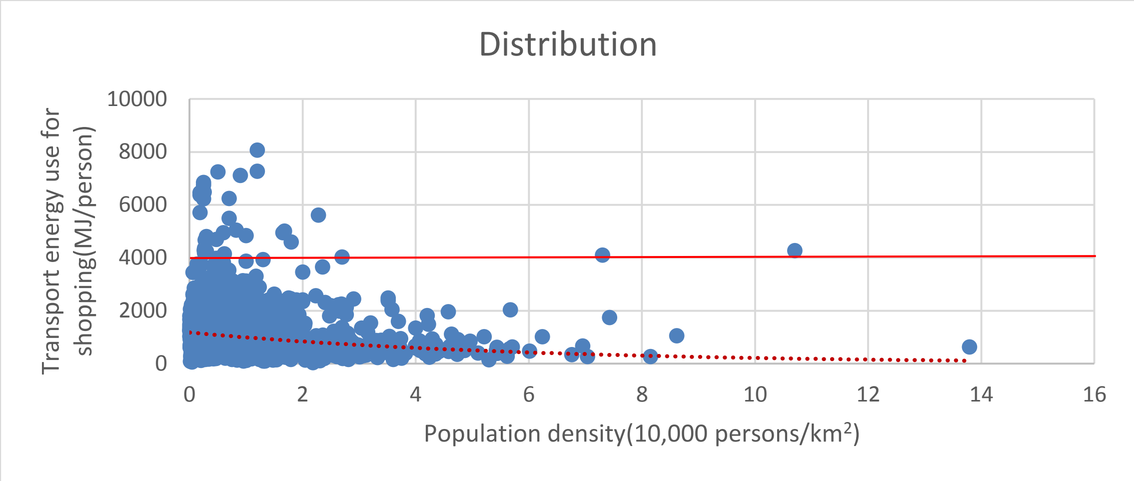


Figure 11. Correlation between transport energy use and population density in Beijing

The ratio of population with adaptive capacity greater than 25 percentile and 75 percentile were calculated in Beijing and Christchurch respectively (Table 5 and Table 6). In table 5, there is no much difference between Beijing and Christchurch in terms of meeting essential shopping activities, most essential requirements can be accessible within short distances. Nevertheless with regard to the walking accessibility, Beijing is better than Christchurch with 20 percent of residents being able to shop within 1 km. In table 6, the result of Christchurch is slightly better than Beijing, nearly half of population could realize necessary shopping activities without motorization requirement, however the ratio of people in Beijing who can realize their necessary shopping activities is less than 20 percent although its shopping facility density is much higher than Christchurch. It is because in megacities, the increasing shopping facilities are more dispersed with the sprawling development of urban area, leading to more travel demand and longer trip distance (See Table. 3).

City	Ratio of people with zero transport energy consumption adaptive capacity		
	In 1km	In 3km	In 5km
Beijing	20%	53.4%	70%
Christchurch	11.4%	63%	80%

Table 5. Comparison between Beijing and Christchurch by 25 percentile shopping value

City	Ratio of people with zero transport energy consumption adaptive capacity		
	In 1km	In 3km	In 5km
Beijing	4%	12%	17.8%
Christchurch	6.7%	18.4%	43.4%

Table 6. Comparison between Beijing and Christchurch by 75 percentile shopping value

6. Conclusion

The model of this research presents a quantitative method to characterize shopping activities from the perspective of transport energy consumption. It combines Huff shopping model and Gravity model with limited travel survey data to calculate shopping transport energy use, in which a novel method to quantify the ranking of shopping facilities and relating travel patterns was proposed. Simply by shifting motorized trips that could be performed by walking and cycling, the potential of non-motorized travel patterns can be analysed based on distance bins. The model was applied to two different cities to compare the influencing factors that can contribute to the reduction of transport energy use. The results provide evidences that the development in the city centre can lead to less travel energy consumption and shorter trip distances, higher population density can help to decrease motorized trips and a small-medium sized city might has higher adaptive capacity in meeting necessary shopping activities than a large city. For megacities like Beijing, the high density development does not necessarily mean to reduce motorized travel demand if the urban boundary is not effectively contained. With the extension of urban area boundary, the average trip distance would be longer resulting in the high possibility of motorized trips. Accordingly, how to improve public transportation systems to meet longer distance travel demand is the only efficient way to offset the impact of urban sprawling.

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2. Conference papers

2.1 Work Unit City: A Study of the Transport Design for Chinese Small City Urban Form

Abstract

Facing environmental degradation and peak oil, western countries have begun to deliberate over the compact city form to decrease energy consumption and air pollution. In the rapid process of urbanization, China however is adopting western sprawling development pattern. In fact, there is a strong organizational basis for Chinese energy-saving development, namely work unit, that is now losing its dominant role. In Chinese cities, the work unit (Danwei), a typical example of centrally planned economy and communism, is not only the critical place for employment, but also the minimal social organization and basic cell for urban form and transport network. During the long period after 1949, the pattern of factory-based community had been pervasive in nearly every Chinese city, which was exclusively prominent in resource-oriented cities such as Daqing and Dongying (oil city), Datong (coal city) and Anshan (steel city). A case study explores basic structure and transportation networks of work unit that is represented by 'small and all-inclusive' manifestation comprising all kinds of facilities and social services within walkable distance. Based on the qualitative analysis relating to adaptive potentials of

work unit in the context of energy constraints, a number of future transition plans are proposed to favor urban sustainable development. The risk to the work unit is its high dependence on the presence of factory, in fact, with the massive collapse of state-owned enterprises in the 1990s, the function of work unit started to decline in the course of economic reform. However its highly-mixed spatial form and stable social structure still provide references for future low carbon urban design with high resilience to energy constraints.

1. Introduction

When it comes to energy crisis or possible oil depletion, for the time being, it is not extremely serious to arouse public interests on energy conservation in many western countries. It is optimistically believed that the oil resources are still abundant enough to be extracted for several hundreds of years. In fact, the peak oil and subsequent decline is no longer a subject of speculation, it is emerging as a relevant planning issue (Krumdieck, 2010). Despite the possible oil supply decline, the massive oil demand from developing countries such as China and India has maintained rapid growth. It is widely acknowledged that China is gradually becoming one of the most powerful economy on the world in the next decades. The energy requirement from China has increasingly grown with the rapid economic growth and strong ambition for modernization. In 1993, China became a net oil-importing country and until now more than half of oil consumption in China is imported from abroad, which likely continue to increase in the future (Figure 1). As might be imagined, the whole world would not sustain the giant demand from China if it remains current extensive development. Therefore the difficulties in addressing China's energy consumption problems are not only its own issues, but to some extent the common concerns for all human kind.

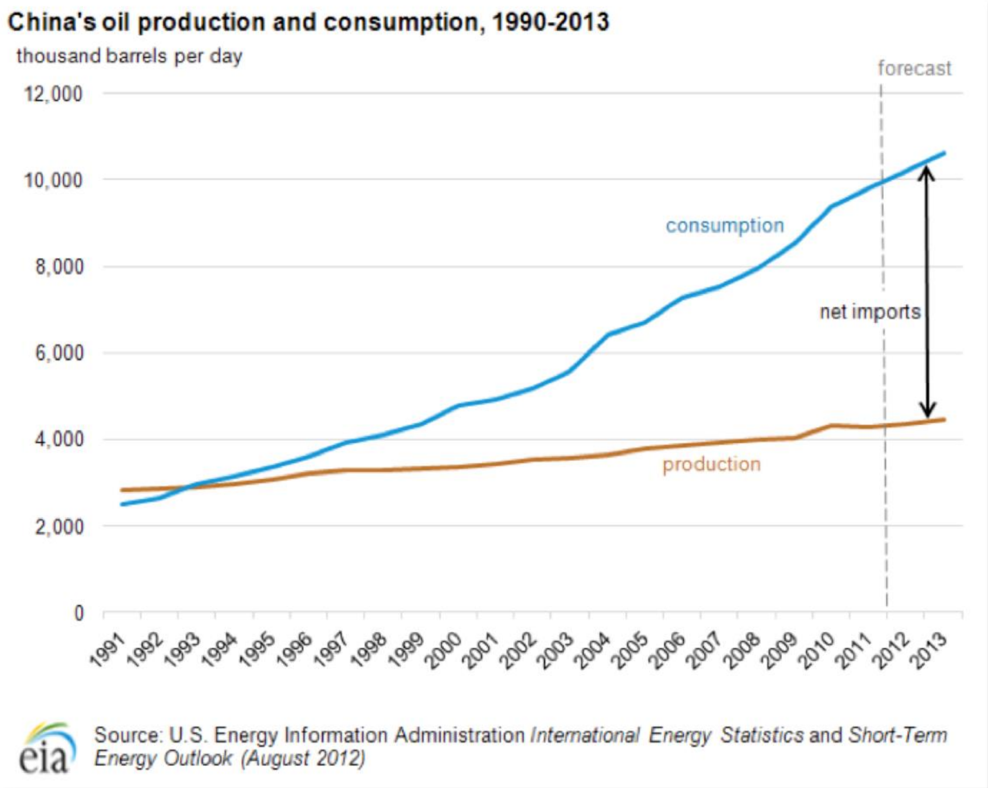

Figure 2-1. China's oil production and consumption

According to the IEA statistics, the transportation sector accounted for over 40% of oil demand in 2010, with motor gasoline, gas/diesel oil being the main transportation fuels (IEA, 2012), so it is necessary for Chinese decision-makers to understand transport energy use at various levels to address energy security, climate change mitigation and environmental pollution abatement. In reaction to these issues, there are two pathways to sustainable transport systems: One is the development of technical innovation (e.g. new energy vehicles and new materials), the other one is the enforcement of social management policy (e.g. pricing system, transportation rule and restriction on driving). Apart from that, transport energy use has been correlated with urban form, e.g. the spatial land use and transport system (Kenworthy and Laube 1999). It is widely acknowledged that the locations of human activities determine the spatial interactions or trips in the transport system, which is also the basic rationale of traffic models (Michael, 2014). Basically, urban form and transport are mutually intertwined, the changes in transport system could affect urban development and location choices of households and enterprises, and the changes in land use could influence the number of trips and mode choices (Paul, 2014).

Facing environmental degradation and peak oil, western countries have begun to deliberate over the compact city form to decrease energy consumption and air pollution, China however is resembling early western urban sprawl pattern during its urbanization, which leads to particularly acute transportation problems such as traffic congestion and air pollution. Due to the resource availability problems in China, there is no enough space for transport infrastructure to accommodate a large vehicle fleet and the negative impacts of massive motorization in China will be more serious if the dependence on motor vehicle is not effectively controlled (Kenworthy & Hu,2002). Accordingly it is necessary for China to explore development potentials in existing systems to promote the sustainability of economy, society and environment.

In fact, there is a strong organizational basis for the Chinese energy-saving strategy, namely the work unit, that is now losing its dominant role. During the long period of Communist regime in mainland China, the work unit (Danwei), a typical example of centrally- planned economy and communism ideology, was not only the critical place for employment, but also the minimal social organization and basic cell for urban form and transport network. It had played an important role in managing Chinese daily life, but with the social development especially as the consequence of market-oriented economy, diversified living styles and varied requirements increasingly marginalize the work unit but with more demand for energy use. This paper intends to reexamine the function of work unit in the history of Chinese development and its implication in future urban transport planning. It begins with the review of the history and background of the work unit. Then it describes the basic structure of the work unit and relating transportation network using an oil city as a sample. The analysis on the adaptive potential of the work unit for constrained oil supply is then presented, which is followed by the transition plan for future urban transport design. Finally the conclusion and some recommendations on future works are also explained.

2. A historical review of work unit in China

The work unit (Danwei), in a sense, was an outcome of Communism ideology instead of the result of urban natural growth. According to classic Marxism theory, the socialization of human life is the radical characteristic of socialist society. In this society, the state-owned enterprise is responsible for the allocation of property including food, salary, welfare and living services. In addition, the Chinese traditional gregarious living habit based on intimate human relations such as the same blood and workplace made it possible that the compact community is widely acceptable by most people. For example, most people living in the same village in Chinese rural areas have the same family name, which means they might be originally from the same ancestor. Therefore, wherever property acquisition can accommodate it, the workplace becomes the principal unit around which domestic and social activities are linked, Danwei has become a term used to signify this spatial integration of work, residence, and social life in cities organized by the Communist Party of China (CPC) (Bjorklund, 1986).

Prior to Chinese economic reform starting in 1978, the pattern of factory-based community had been pervasive in nearly every Chinese city, which was distinctively prominent in resource-oriented cities such as Daqing (oil city), Datong (coal city) and Anshan (steel city). Even among comprehensive megacities like Beijing and

Shanghai, the legacies of work unit are still visible everywhere. It was not only an economic organization for industrial production, but also a rigid political hierarchy to avoid social chaos and free migration. Lü & Perry (1997) argued that as a basic unit in the CPC political order, the danwei is a mechanism with which the state controls members of the cadre corps, monitors ordinary citizens, and carries out its policies. Once one had an opportunity to work as a formal employee in a state-owned factory, it meant that the essential living needs including jobs, housing and medical care would be guaranteed, which was deemed as a stable social status without too many concerns on subsistence. In particular, the work unit assumed the full responsibility of housing provision for its employees, this system left the employees no choice but to live in houses allocated by their affiliated Danwei, because there was virtually no housing market from which one might buy or rent a house (Wang & Chai, 2009). In the aspect of socioeconomic organization, this special institution is represented by 'small and all-inclusive' manifestation comprising all kinds of facilities and social services (schools, hospitals, parks, and grocery stores) within walkable distance, the purpose of which is to act as an accessory service to support industrial production. Figure 2 (Miao and Zhen, 2009) depicts a sketch of a small-scale work unit enclosed by walls in Beijing. Living in apartments allocated by their factory, employees can buy food in local grain store or eat in centralized canteens, go to work by walking or riding bicycle, send their children to kindergarten or school, enjoy free medical treatment in local hospital and so forth. However any departure to other places must be permitted by superior officials, which is also applicable to any entry into the work unit likewise. Moreover they didn't have too many choices to enjoy spare time due to the restriction from political circumstance.

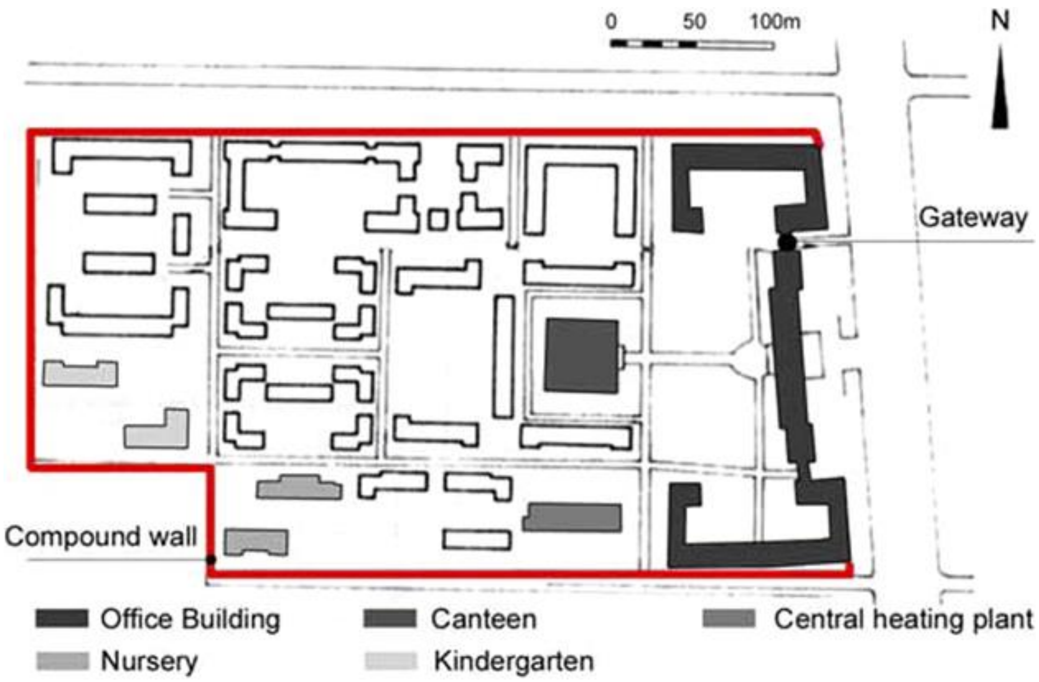

Figure 2-2. A small-scale enclosed compound (danwei) with one entrance, Beijing (Miao and Zhen, 2009)

After Deng Xiaoping's reform and open policy being implemented from 1978, China steadily extricated itself from the bondage of ideology and stepped on to the market-oriented route into modernization. At the same time, the state-owned enterprises and accompanying work unit community were affected by the liberalization of Chinese economy as well. Some free markets were permitted to exist in the work unit, which indeed facilitated local life. The authority gradually relaxed its grip over the work unit to make local people have more freedom to choose their own activities. Especially from 1992 when CPC determined to implement overall market economy, the state-owned enterprises encountered huge challenges from private companies and foreign competitors, some were completely bankrupt, some industries vital to national security and development fortunately survived but with large transformation in many aspects. For employees in the closed factories, the ultimate destiny were unemployment and the loss of relating welfares from former employers, which obliged them to find other chances outside the work unit to sustain their livings. Although some state-owned enterprises perform better than before, their social responsibility for their employees is gradually shrinking. Thus the work units previously affiliated to them have undergone substantial changes. Many facilities including schools, hospitals and parks either become independent or are transferred to local city council to manage. People have now more freedom to choose their own life and the function of work unit fails to meet growing diversified requirements thanks to socioeconomic development.

3. A case study：The Spatial structure and transport network of a work unit city

The forms of work unit in China are different in accordance with the function of cities. In the aspect of scale, a large-sized work unit tended to have separate residential compounds adjacent to the compound containing the industrial plants and administrative offices. Indeed, the sheer size of some of these danwei gave them the appearance of small cities or industrial towns (Bray, 2005). A smaller work unit usually was enclosed by walls and could only provide basic needs for their employees such as dormitory, canteen and medical clinic, which is popularly distributed in large old cities. In this paper, a classic work unit city called Dongying would be introduced as an example to analyze its spatial structure and transport networks.

Dongying is a newly built oil city in the north of Shandong Province with the purpose of serving the production and infrastructure of local oil field (Shengli Oilfield), which is located near the Yellow River estuary into the Bohai Sea (Figure 3). At the 2010 census, there are around two million people living in its administrative area of 7923 km^2, one fourth of which are employees and their families affiliated to Shengli oilfield. A large portion of local economy is dependent on oil and relating industries. The per capita GDP of Dongying is ranked 4th among Chinese cities. With the close connection with Shengli Oilfield, Dongying is a classic work unit city and has its unique characteristics. Before it was established in 1983, there were approximately 30 subordinate companies distributed around this area, which had different functions for oil production. For instance, Huanghe Drilling Company is a secondary work unit specializing in drilling procedure before extracting underground oil. For a long period even after the establishment of Dongying city, the leadership of Shengli Oilfield also played the role in city government administration. With the improvement on city function and for the sake of efficient management, Dongying city is now on the way out of its adherence to the oilfield.

Figure 2-3. The location of Dongying

Dongying city is divided into the west district as the base of Shengli Oilfield, and the east district as the site for municipal government. Figure 4 shows the basic structure and organizational relationship of Dongying city and Shengli oilfield. The base of oilfield is surrounded by different work units (green-colored) with transportation networks to each other, there are three counties called Kenli, Guangrao and Lijin under the jurisdiction of Dongying government. For majority of employees in the oilfield, the base of oilfield is traditionally viewed as their own city center. In city center the best services and facilities of Dongying including upmarket restaurants and shopping malls, first-class hospitals and high schools are centralized along an east-west road between. With respect to transportation system, a fairly complete basic trunk network between inner-city and inter-city has been accomplished. Only one freight-based railway connects the oilfield with another oil refinery south of Dongying. As a production-oriented city, the tourism and cultural facilities of Dongying are inadequate due to its harsh natural environment and short-term historical accretion. For relatively wealthy people, the enjoyment in traveling to other cities is more fascinating than just attending local activities. With the construction boom in property development nationwide, the living amenities in city center have attracted people formerly living in work units to buy houses in good areas. While more population and vehicles are aggregated in the city center, congestions and overcrowding are becoming more serious than before. Generally for the employees and their families living in all kinds of subordinate work units, the sense of belonging to the oilfield is stronger than their concerns on Dongying's development.

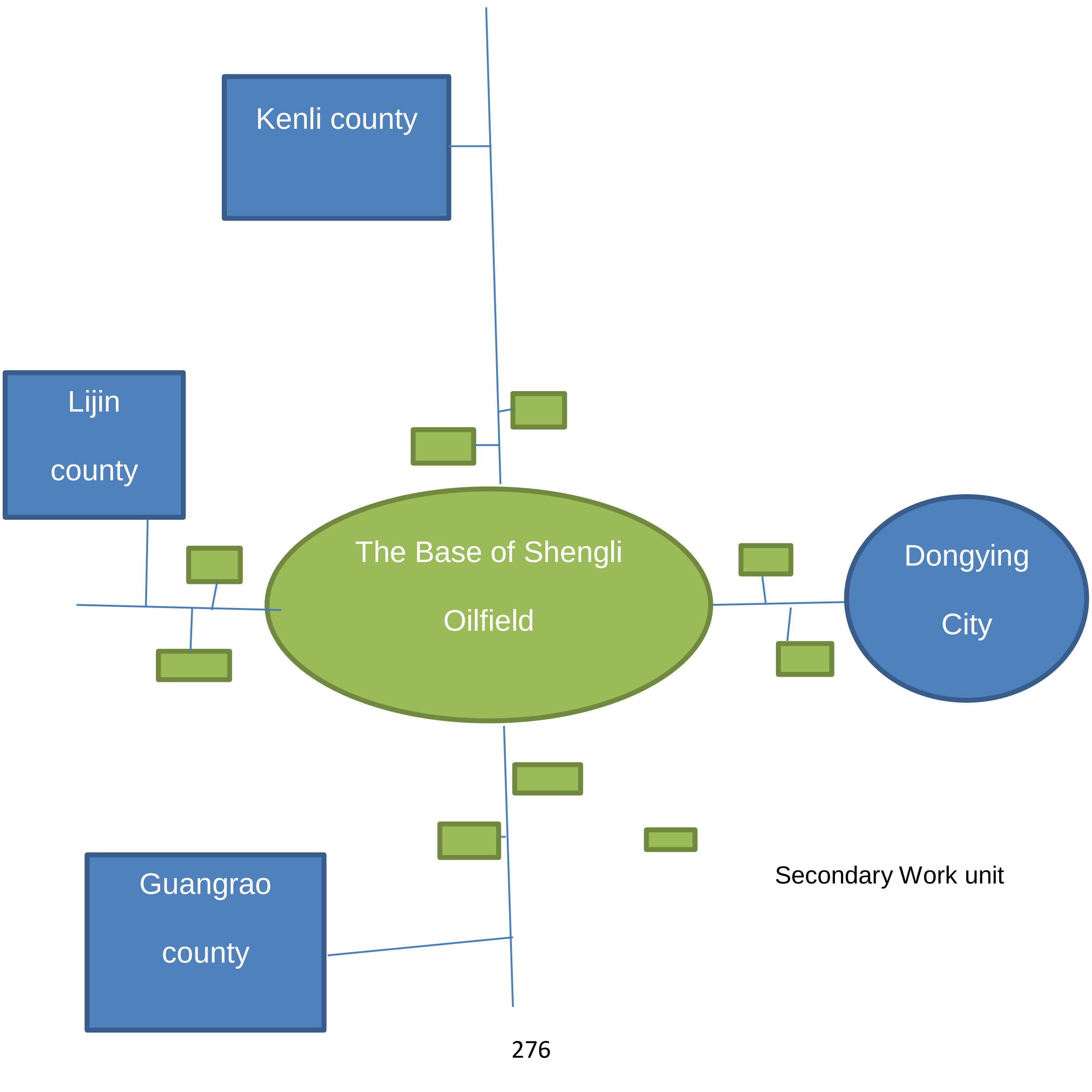
Kenli county
Lijin
county
The Base of Shengli
Oilfield
Dongying
City
Guangrao
county
Secondary Work unit

Figure 2-4. The city-oilfield compound structure of Dongying

Take Huanghe Drilling Company (HDC) as an example (see fig.5 and fig.6), it lies between the city center and another county town called Kenli with the distance of about 6 km and 8 km respectively. It is populated around 50000 people in the area of 3 km^2 where almost all kinds of institutions and facilities are distributed in a compact way. Some third work units belonging to HDC and other drilling-related companies are also located in this area, the majority of people living in company-funded apartments is comprised of HDC's employees and their families. Besides, there is an agriculture site called Dongan in the east of HDC to provide food as well as solve employment problems for some employee's wife and children. Even though small number of employees live in other places outside HDC, the company bus can offer convenient transportation for them to choose. The necessary facilities such as schools, hospitals, markets and parks cover local basic needs. The minimum distance to the fringe of city center is about 6 km, the average trips to city center per month for local people is estimated to be 1~2 times. There are several road networks connecting work units with city center, through which people can ride a bus or car, even cycling to city center is not unusual at present time. For most of the year, inhabitants residing in different apartment blocks can have access to the workplace, schools, hospitals, park, supermarket in around 5~10 minutes by walking or cycling. There are few roads crossing the community that connect main transport networks outside, the mixed walking streets and pathways are most common in this area.

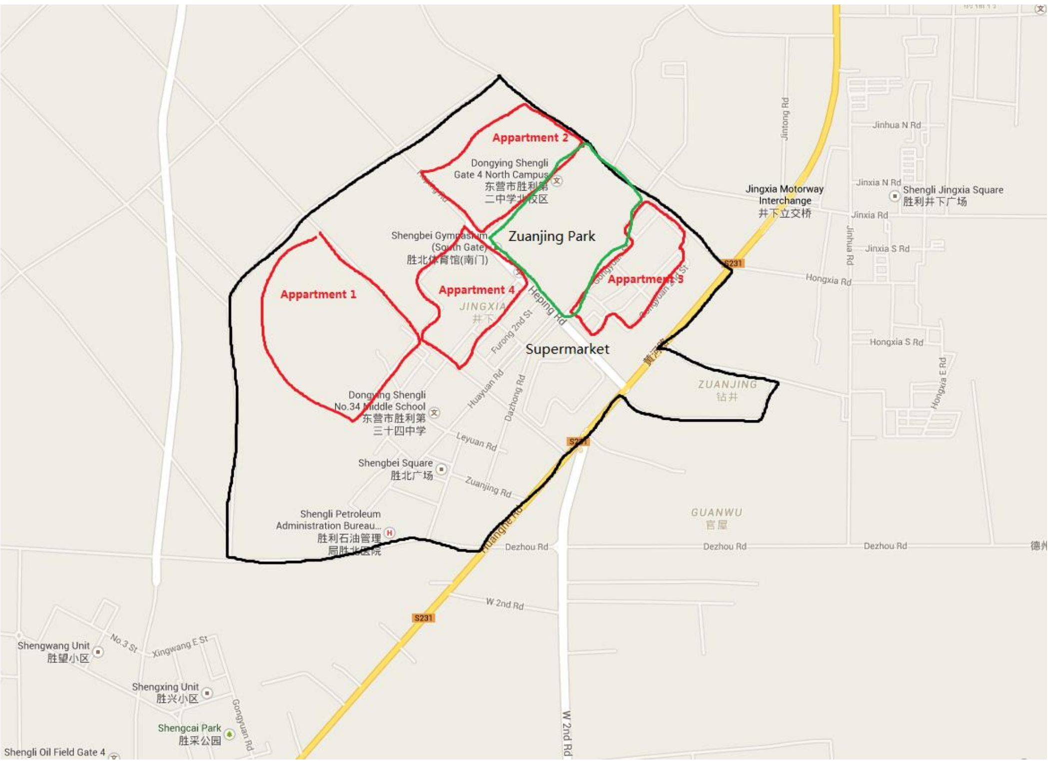

Figure 2-5. The basic spatial structure of Huanghe Drilling Company

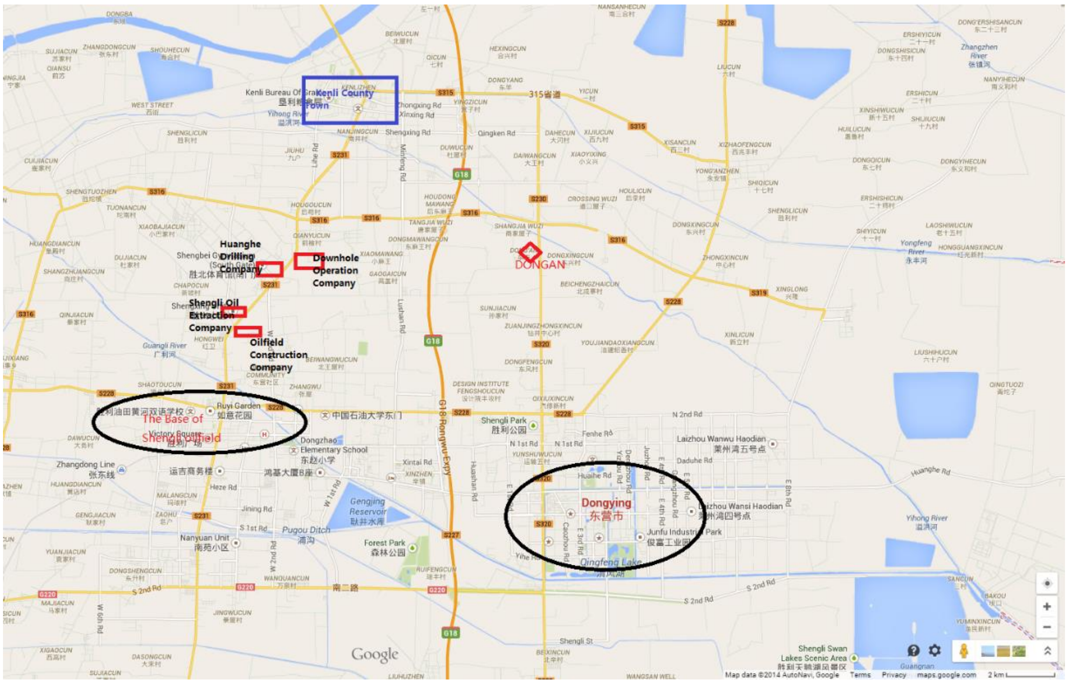

Figure 2-6. The geographical distribution of work units nearby HDC

Before 2000, cycling was the main transport mode for most families living in work units. Typically for the people living within the distance of 5 km, cycling to city center was more preferable if they want to avoid the inconvenience of taking a bus. As the quality of life is gradually improved, car ownership has been on the rise. However most cars are mainly used by young people, walking and cycling are still widely pervasive among old people and students. In addition, because of the work arrangement from above, some young people have to work in other work units or city center, which leads to an increasing divergence between their jobs and housing with their parents.

4. Adaptive Potential analysis of the Work Unit

In the course of urban development in China, the urban sprawling form is a prevailing tendency to meet future economic requirements. Theoretically, it might be inevitable that the market economy encourages more freedom in the migration of production factors including capital, resource, technology and labor force. However the blindness of market power and the disorder in economic transition will result in excessive energy use and random expansion, which would in turn deteriorate environmental protection and social harmony. Being a legacy of centrally-planned economy, the work unit as described above also supports the view that more balanced jobs-housing relationships may lead to shorter commuting trips, increased usage of non-motorized transport mode, and reduced travel, which may imply less energy consumption and less emission of air pollution (Cervero, 1989). Therefore, finding inner-city potentials to realize the balance between development and energy constraints would be significant to cope with future possible peak oil or energy shortage.

Active Mode Accessibility (AMA): Accessibility is defined as the ability to access goods, services, activities, and destinations or “what, and how can it be reached, from a given point in space” (Bertolini et al., 2005; Yigitcanlar et al., 2007). At present, accessibility is gradually becoming a good metric to evaluate urban transportation systems. AMA is defined as the proportion of activities that can be reached by human-powered transportation (such as walking, running and cycling). It is obvious that AMA is negatively related to oil use, an urban transportation system with higher AMA is less reliant on oil for transportation. Generally for the city center, the accessibility is very high on account of its convenient connectivity and densely distributed facilities. In the case of work unit, the shorter distance coverage and all-inclusive micro-facilities also make it more accessible by all kinds of modes. By analyzing the spatial structure in HDC, we can assume that the AMA to key destinations of work unit is 100%, the minimum transportation energy use is 0, which explicitly indicates that the work unit is resilient to energy risks such as fuel price shock and possible energy shortage.

Self-sufficient ability for sustainable living： Because of remote geographical location and adverse natural environment, the original design for Shengli oilfield was to be concentrated on self-sufficient development so that all necessities could be satisfied as much as possible. As mentioned in the case of HDC, there are plenty of agriculture sites where they are suitable for plants to grow, which provide food for employees in work units in a way of welfare. Until recently, the work unit assumed the responsibility for the procurement of welfare including some food and daily necessities unavailable in local environment. Also domestic gas and electricity are provided by oilfield and local power grid respectively, which somewhat reduce the reliance on outer energy resources. In addition, some collective living facilities such as factory canteens, leisure square and retirement center bring certain convenience for local inhabitants. For the older generation of employees mostly coming from poor villages, the necessary services basically meet their primary needs. It is believed that with the improvement on living quality and progress in society, more advanced requirements would not be locally satisfied and as a consequence, the trade with outside places would become frequent resulting in more energy use eventually. However this pattern of inward development associated with the supply of necessities still remains enormous potentials to achieve energy conservation and harmonious growth.

Demographical mobility: It is well known that social stability is the cardinal task for CPC to manage and control Chinese people. Any form of riot and disorder would not be tolerable by CPC government, which is also a key criteria for evaluating local official political achievement. For a country with the largest population on the world, stable social structure and less mobility ought to be a sensible way to approach the balance between economic growth and social harmony. Noticeably, the population in Dongying is relatively small and the distribution of population density is uneven. Apart from the highest density in the long narrow area between the base of oilfield and the city government, most people live in work units and county towns separated by undeveloped lands. Compared to the growing urban mobility, the daily commute in Danwei community is always ‘static’, of no energy consumption (Chen, Zhu & Ren, 2012). In general, for the work units 3 km away from city center, most activities can be performed within the area of work unit, which leads to a high AMA and a limited mobility in the city area with less energy use. For the work units closer to city center, the demographic mobility to city center is higher but essential activities inside work unit are still prevailing. However on weekends, the requirement for consuming and entertainment in city center certainly activates travel demand and subsequent urban mobility.

Localized Employment: At present, after solving problems of food and clothing, the primary concern for China government is just how to help younger generation to find appropriate jobs regardless if it is a state-owned or a private enterprise. In Chinese context, a stable job has been regarded as a representation for personal future development. Owing to the one-child policy and Chinese tradition, a large number of employees prefer their children to work and live with them together. In fact, most younger people choose to work in Shengli Oilfield after graduation and the oilfield has been responsible for localized employment although it is opposite to the requirement of reformation and management. Even if some younger people don't work at the same work unit as their parents, they can take a company bus to commute every day. Accordingly, localized employment not only facilitate family reunion but also shorten the distance of jobs-housing commute.

5. Transition Plan for Future Sustainable Development

As a newly built city, Dongying has great space and opportunities to achieve sustainable urban transportation systems. However it is estimated that some new trends would be emerging in the future along with the infrastructure of Dongying, which could be detrimental factors for its resilience to energy constraint:

a. Some people begin to move out of the work unit to buy affordable commercial housing instead of welfare apartment.

b. The car ownership is on the increase although to a greater extent it is a representation of social status rather than practical necessity.

c. The new facilities and constructions are primarily situated in city center.

In reaction to above issues, Shengli Oilfield and Dongying city should make best of the work unit with regard to the concerted development of energy, environment and society. Based on the efficient application of work unit, some transition plans should be explored as follows:

5.1 The distance between housing and work units is supposed to be as short as possible.

Owing to the growing demand derived from social development, more lands would be used for housing. Since the authority of land management has been transferred to Dongying city government, the work units of Shengli Oilfield have more difficulties in building welfare apartment for their employees in their own area. As a result, the collective land purchase funded by the oilfield has begun to arise in some places, but the locations are far away from work units. To resolve this problem, the coordination between the city and the oilfield is crucial to offer best geographical position for surrounding work units. In light of the advantage in the flexible connectivity among different work units, the multiple coverage housing site with high AMA to adjacent work units could be found through GIS tools.

5.2 Realizing a reasonable distribution of facilities in accordance with socio-economic situation and work unit geographical characteristics

As far as the current situation is concerned, the essential requirements including primary education, medical service, supermarket have already been satisfied with a high AMA in each work unit, the attraction of new facilities in city center and the increase of car ownership nevertheless contribute to the augment in vehicle trip. According to Dongying’s development plan (Dongying Planning Bureau, 2010), the future focus will arrange new facilities and housing along the long narrow area between west district and east district, which neglect the requirement from inhabitants living in work units outside city center. Take HDC as an example, if some shopping malls and leisure centers could be built in Kenli county, not far away from HDC, there would be at least three advantages: (1) It could be seen as a political achievement for local officials to promote local economic prosperity. (2) It could attract more people in neighboring work units to come for consumption. (3)The bypass flow to the north would alleviate traffic pressure and subsequent congestion in city center.

5.3 High-density redevelopment between work units

Based on the fact that a vast tract of land between work units has not been fully utilized, it is useful for Doingying city to pay more attention to the mixed land use and strategic development with high AMA to each work unit in pursuit of health, security and sustainability. Actually, the oilfield has made some efforts to merge some geographically adjacent work units into one community in terms of administration. However the connections between them are limited and the matching facilities still remain separated from each other. More importantly, the homogeneous level of service and similar facilities among work units decrease the mutual mobility resulting in more trips to city center for higher level consumption. Therefore, redeveloping land use and upgrading the level of existing facilities would be more challenging to realize truly organic combination of work units.

5.4 Implementation of city multifunction

For an oil-reliant city as Dongying, the single economic structure is an adverse factor to adapt to changing circumstances. The greatest risk of work unit is its high dependence on the presence of factory, in fact, with the massive collapse of state-owned enterprises in the 1990s, the function of work unit started to diminish in the course of economic reform. Fortunately some resource sectors crucial to national security had survived in the shock of reformation thanks to government protections. However facing the challenges from possible oil depletion, Dongying city has to reconsider its future pathway toward sustainable development. In association with the location of work unit, the oilfield and city could cooperate together to realize the balance between economic structure transition and energy conservation. For example, the ample land resource could be fully exploited for more crop planting and animal husbandry aiming at self-sufficiency and convenience for work units. Since each work unit owns one or more agriculture sites, the holistic integration of housing, jobs, site location might optimize AMA and efficiency.

6. Conclusion and Discussion

It is undoubted that China will grow into a giant economy stimulating world energy requirement in the next decades. Nonetheless the risk of peak oil and the accompanying imbalance between world oil supply and demand would be a serious obstacle for China to overcome. Although some technical progress make us more confident about building an environmentally friendly society in the future, the feasibility of renewable energy transport is still far away from reality on account of troubles in its commercialization and popularization. Therefore, it is necessary for us to redirect our thoughts from the problem-solving at the bottom end of transportation systems to the upstream design with ground-breaking ideas. In face of the predicament between development and sustainability, especially during the process of urbanization in China, how to design urban form in consideration of energy constraints and comprehensive harmony is a challenging issue for China government.

The current imitation of western urban sprawl pattern in China is worth serious consideration in terms of sustainability, furthermore, the enhancement on efficient use of public space and maximization of collective interest should be highlighted during city construction and land conversion in the long run. Although the work unit is a little obsolete in terms of economic growth, its compact design and complete function for basic necessities still offer a good foundation for future transition plan. As a production of centrally-planned economy, the original thought of work unit was just to facilitate employee’s living without considering whether or not it is energy-consuming, but interestingly, it has great potentials to resist the future risk of energy crisis and high resilience to possible oil shortage in that its high AMA and all-inclusive services indeed decrease physical travel requirement. In the case of Dongying city, the coexistence of oilfield enterprise and city government can organically integrate the work unit with urban form to basically achieve the urban-industrial-economic complex with less transportation energy use.

In the light of qualitative analysis on work unit in this paper, more rigorous and quantitative investigation should be strengthened in the future research. In addition, in view of the particularity of oil city, the scale of local oil industry would presumably shrink given the possible oil depletion in the future, resulting in less localized employment and recession of city economy, which also could negatively affect its sustainable development.

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2.2 To phase out or preserve? The work unit design and its implications for sustainable and resilient urban development

Abstract

Facing environmental degradation and possible oil depletion, western countries have begun to deliberate over the neo-traditional development to decrease oil reliance and mitigate carbon dioxide emission. In the rapid process of urbanization, China also encounters urban diseases that the massive motorization transportation has brought about. In fact, there has been an energy-efficient livable dwelling type in China, namely the work unit (or Danwei community), that is represented by a 'small and all-inclusive' neighborhood-like compound consisting of a full set of facilities and social services within walkable or cyclable distance to meet essential living requirements. Besides a brief historical review on the socioeconomic characteristics of work unit, this paper mainly centered on the spatial structure of work unit to explore its potentials in reducing motorized transportation. Based on short distance bins, a series of measurement were proposed to quantify the accessibility, complexity and the degree of mixed land use. A case study in Beijing was conducted to evaluate the low carbon potentials in work trips and non-work trips respectively. The research findings revealed that the work unit remains obvious advantages in promoting active mode work trips, however the differences in accessing nearby amenities between

the work unit group and non-work unit group are not remarkable. Although the work unit seems not to keep pace with the development of market-orientated economy, its unique layout and spatial design still provide good reference for the ideal of livable, accessible and integrated community.

0 Introduction

As is known to all, China has become the second largest economy on the world and still maintains a strong momentum towards modernization and urbanization. Meanwhile, the energy requirement from China has increasingly grown with the rapid economic growth. In 1993, China became a net oil-importing country and until now more than half of oil consumption in China is imported from abroad, which likely continue to increase in the future (Figure 1, EIA, 2012). As might be imagined, the whole world in the future would not sustain the giant demand from such developing countries as China or India if it remains current extensive development. Therefore the difficulties in addressing China's energy consumption problems are not only its own issues, but to some extent the common concerns for all human kind.

Facing environmental degradation and potential oil depletion, western countries have begun to deliberate over the New Urbanism and Neo-traditional development to decrease automobile dependency and mitigate carbon dioxide emission, China however is resembling early western urban sprawl patterns during its urbanization, which leads to particularly acute transportation problems such as traffic congestion and air pollution (Davis et al.,1995). Due to the limitation in resource availability of China, there is no enough space for transport infrastructure to accommodate a large vehicle fleet and the negative impacts of massive motorization in China will be more serious if the dependence on motor vehicle is not effectively controlled (Kenworthy &

Hu,2002). Accordingly it is urgent for China to explore new approaches especially in existing systems to promote the sustainability gains and balance economy, society and environment concerns.

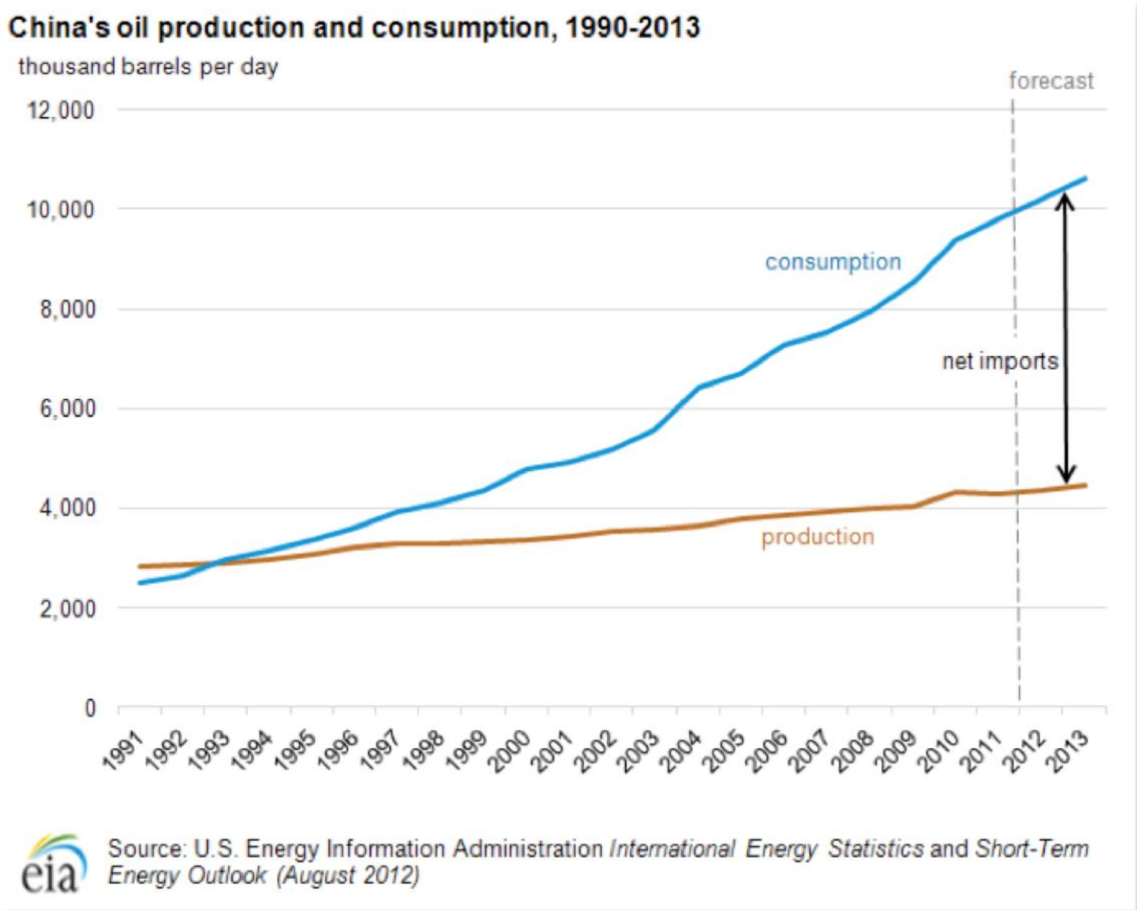


Figure 2. The gap between oil production and consumption of China

In fact, there is a good foundation for the Chinese energy-saving strategy, namely the work unit, that is now losing its dominant role. During the long period of Socialist regime in mainland China, the work unit (Danwei), a typical example of centrally-planned economy and communism ideology, was not only the critical place for employment, but also the minimal social organization and basic cell for urban form and transport network(Bray,2005). It had played an important role in the management of Chinese daily life, but with the social development especially as the consequence of market-oriented economy, diversified living styles and varying requirements increasingly marginalize the work unit but with longer commuting distance and more demand for energy use(Chai, 2014). This paper intends to reexamine the function of work unit in the history of Chinese development and its implications in low carbon development. It begins with the historical review of work unit development and a qualitative description about its layout and spatial structure. Next it presents the methodology for quantifying the low carbon potentials with a number of metrics including Accessibility, Complexity and Mixed Land-use. A case study in Beijing then is carried out using this methodology to compare the low carbon transport potentials between the work unit and non-work unit. The research findings show that the work unit has approximately 0 carbon emission in the aspect of working trips, however there is no much difference in accessing living facilities within short distance between work unit and non-work unit.

1 Historical Review

The work unit (Danwei), in a sense, was an outcome of Communism ideology instead of the result of urban natural growth. According to classic Marxism theory, the socialization of human life is the essential characteristic of socialist society. In this society, the community is responsible for the allocation of property including job, food, welfare and living services. Bearing resemblance to the ideas from Former Soviet Union, the work unit in China emerged as a specific response to the problems of resource allocation, production organization and social governance (Liu 2000; He, 2003). Therefore, wherever property acquisition can accommodate it, the workplace becomes the principal unit around which domestic and social activities are linked, Danwei has become a term used to signify this spatial integration of work, residence, and social life in cities organized by the Communist Party of China (CPC) (Bjorklund, 1986).

Prior to Chinese economic reform starting in 1978, the pattern of factory-based community had been pervasive in nearly every Chinese city, which was distinctively prominent in resource-oriented cities such as Daqing (oil city), Datong (coal city) and Anshan (steel city). Even among comprehensive metropolis like Beijing and Shanghai, the legacies of work unit are still visible everywhere. It was not only an economic organization for industrial production, but also a rigid political hierarchy to avoid social chaos and free migration. Lü & Perry (1997) argued that as a basic unit in the CPC political order, the work unit is a mechanism with which the state controls members of the cadre ranks, monitors ordinary citizens, and carries out its policies. Once one had an opportunity to work as a formal employee in a state-owned factory, it meant that the essential living needs including job, housing and medical care would be guaranteed, which was deemed as a stable social status without too many concerns on subsistence. In particular, the work unit assumed the full responsibility of housing provision for its employees, this system left the employees no choice but to live in houses allocated by their affiliated Danwei, because there was virtually no housing market from which one might buy or rent a house (Wang & Chai, 2009). In the aspect of spatial structure, this special institution is represented by 'small and all-inclusive' layout comprised of diversified facilities and social services (schools, canteens, hospitals, parks, and grocery stores) within walkable distance, the purpose of which is to act as an accessory service to support industrial production. Figure 2 is a sketch of a small-scale work unit (2km×2km) in a certain Chinese city. Living in staff apartments allocated by their employer, employees can shop in local living facilities or eat in staff canteens, go to work by walking or riding bicycle, send their children to kindergarten or school, enjoy medical service in local hospital and so forth.

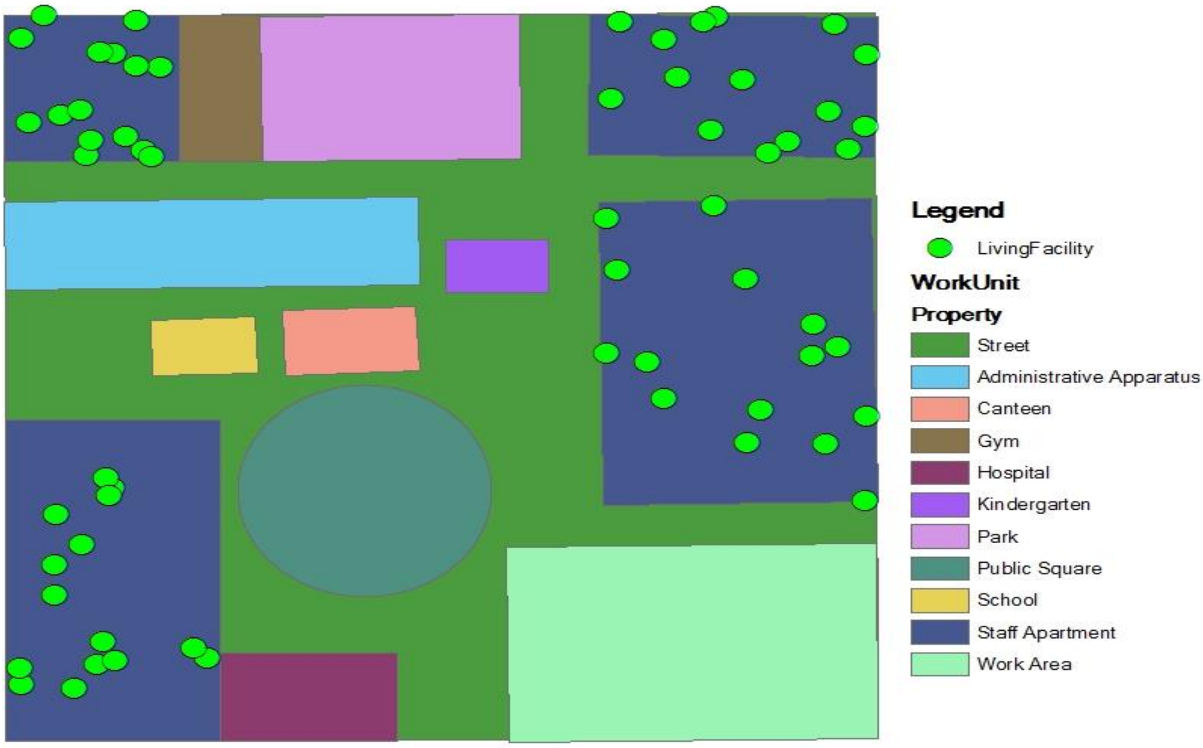


Figure 2. A sketch of small-scale (2km× 2km) work unit in China

(Source: drawn by authors)

Generally speaking, the nature of work unit could be summarized as the following features:

1. Localized employment (or residence). The living space are usually built in the administrative area of factory or as close to working place as possible.
2. Multifunctional layout with high density. For each work unit, the basic living requirement (e.g. shopping, hospitality, education, recreation, hospital) could be accessible within short distance.
3. Enclosed or semi-enclosed community. The transport infrastructure in work unit is represented by streets, walkways or locals with low speed limitation.

After Deng Xiaoping's reform and open policy being implemented from 1979, China steadily extricated itself from the bondage of ideology and stepped on to the market-oriented route into modernization. At the same time, the urban form and socioeconomic characteristics of Chinese cities have also experienced substantial changes (GAUBATZ P. ,1998). The authority gradually loosened its grip over the work unit to make local people have more freedom to choose their own activities outside the work unit. Especially from 1992 when CPC determined to implement overall market economy, the state-owned enterprises encountered huge challenges from private companies and foreign competitors, some has gone completely bankrupt, some industries vital to national security and development fortunately survived but with transformation in many aspects such as relocating their industrial plants to suburb areas(Qiao,2004; Wang and Liang 2010). China's government has abolished the welfare housing system since 1998, in principle all the state-owned enterprises never build staff apartment and most of the affiliated facilities including schools, hospitals and parks either become independent or were consigned to local city council for governance. Meanwhile the commercial residential community has emerged with the social transformation and urbanization in China. Due to the high housing prices in the city center, more and more people have to relocate to suburb area for affordable housing opportunities, which result in job-housing imbalance and possible longer work trips (Zhou, Zhang et al. ,2014). Despite the growing housing market, there are still a large number of workers living in work unit or employer-providing housing units. Moreover, following the way of work unit design, the highly mixed development in the aspect of living facilities is still prevailing in the course of Chinese urban planning (Jenks M et al.,2002; Wang, 2011).

2 Methodology

There are a number of measures to deal with the problems of urban transport system. However the commonly accepted conceptual framework for quantifying the urban sustainability or low carbon potentials is still in question. Jabareen (2006) carried out a thematic analysis on how to address the question of whether certain urban forms contribute more than others to sustainability. In this analysis, seven design concepts pertinent to sustainability are presented including density, diversity, mixed land use, compactness, low carbon transportation, passive solar design and ecological design. According to Litman (2001), Sustainable transportation can be evaluated by measuring automobile dependency: the greater the dependence on automobiles, the less sustainable the transportation system. For the sake of simplification and to avoid the intervention from subjective judgement, the metrics of accessibility, complexity and mixed land use simply based on two physical variables (quantity and distance) were used for analysis.

2.1 Dwelling type classification

Given the differences between China and the West, the Chinese dwelling type needs to be classified as follows:

Work unit: The previously dominant dwelling type in China, mainly situated in the old part of city.

Commercial housing: a newly emerging dwelling type after 1998, which is mainly driven by market force and individual interest.

State apartment: a government-funded dwelling type for low-income residents, mainly situated in the suburb area.

2.2 Transportation activities

Subsistence activities: The work trip is the primary subsistence activity for human beings living. It is assumed that travellers have no much freedom to change their workplace in a short term, the route and frequency of work trip are fixed and stable.

Resilient activities: The activities that are 'discretionary or unnecessary' and relevant to mode choices (e.g. shopping, recreation, hospitality)(Gordon et al.1988;Cevero and RADISCH,1996; Banister et al.,1997). Travellers can decide which place for shopping, whether or not go to a certain place for entertainment. In this paper, only **shopping, hospitality, recreation, hospital and education** activities were analyzed to represent the basic living requirement.

2.3 Terms and definitions

2.3.1 Accessibility

Accessibility is defined as the ability to access goods, services, activities, and destinations or "what, and how can it be reached, from a given point in space" (Bertolini et al., 2005). In this research, the definition from Hansen (1959) was used by counting the number of activities (e.g. shops) available at a given distance from an origin (e.g. the home).

$$A_C^d = N_C^d$$

Where *C* means the category of facility, *d* means the distance bin from origin. N_C^d denotes the number of a category *C* of living facility within different distance bins(Only the distance of 1km, 3km and 10km were considered). With the assistance of ArcGIS, an example of accessibility calculation within 1km travel distance is illustrated in figure 3.

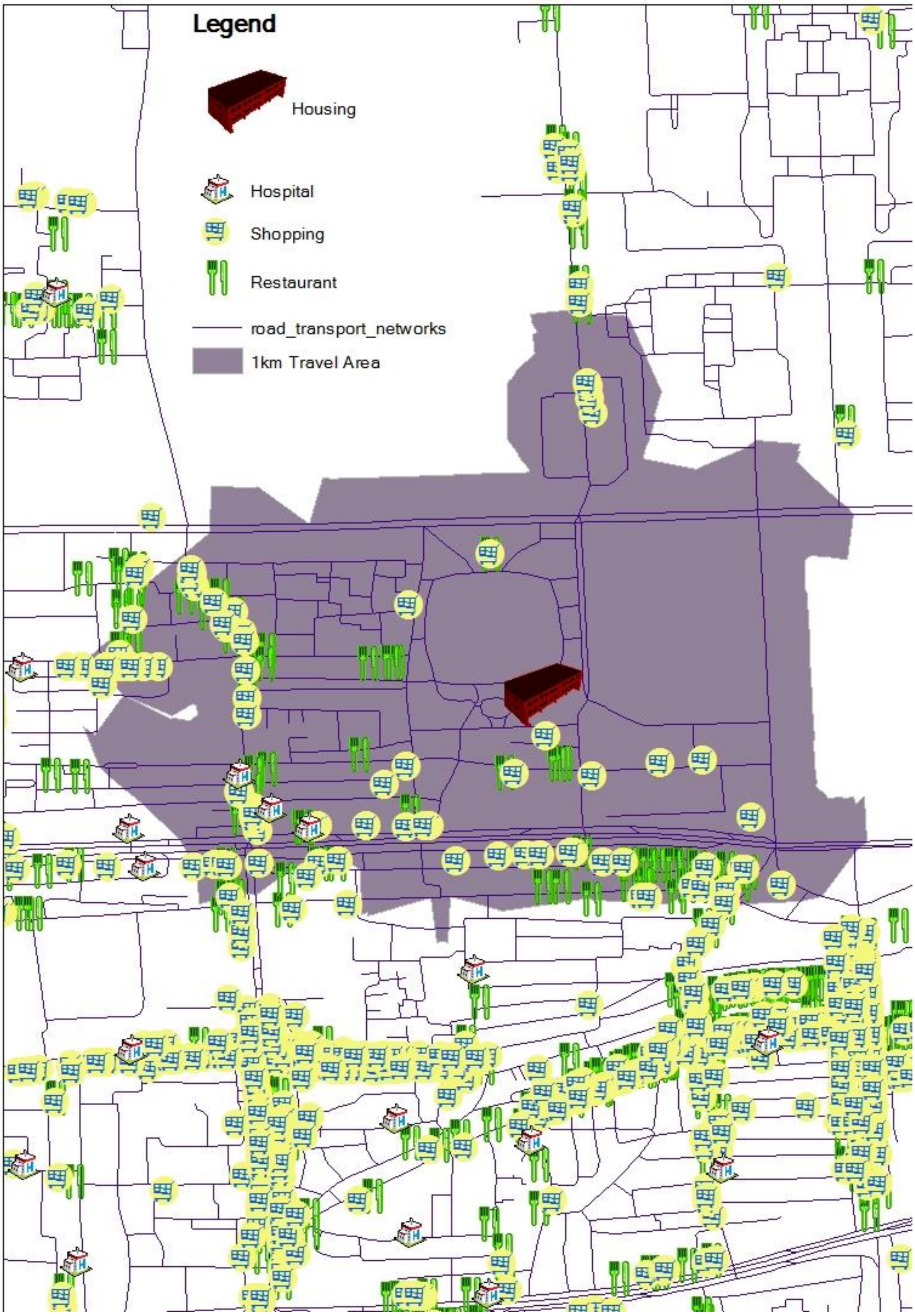


Figure 3. Accessibility calculation in ArcGIS system

2.3.2 Complexity

M. Shannon's information entropy statistic (De Smith MJ et al., 2007) was borrowed in this research to characterize the degree of complexity of land use. The smaller the value is, the lower the level of complexity of land use is, which means all data falls into 1 category, whereas the bigger value means the higher diversification of categories.

$I = -\sum_{C=0}^{n} P_C \ log_2 \ (P_C \ )$ (Note that if $P_C \ = 0$, then $P_C \ log_2 P_C$ =0.)

Where P_C is the proportion of events or values occurring in the C^{th} kind of facility, which is calculated by the following expression:

$$P_C \ = N_C^d / \sum_{c=0}^{n} N_C^d$$

2.3.3 Mixed Land-Use Index

Either the complexity or the accessibility alone can't completely represent the degree of mixed land use. For example, although there is only 1 facility falling into each category of resilient activity (e.g. a combination of 1 grocery store, 1 school, 1 restaurant, 1 hospital, 1 recreation), the value of complexity is quite high (Complexity=2.32). Thus the production of Complexity and Accessibility is employed to quantify the level of mixture of land use. If the complexity and accessibility in a certain distance bin are both high in a study region, the attractiveness to this area would be increased as the result.

$$M= \sum_{c=0}^{n} A_C^d \times I$$

In this paper, it is assumed that the higher value of Mixed Land-Use Index within short distance denotes the higher low carbon potentials for resilient activities.

2.4 Data explanation

Owing to the limitation of data availability, it is difficult to obtain the work trip distance matrix of commuters in different dwelling types. According to the literature review (Liu et al., 2009; Zhang & Chai, 2009; Ma, Chai& Liu, 2011), the average commuting distance comparison was analyzed based on their travel survey data in different neighborhood. All the other datasets on living facilities were mapped in ArcGIS system including neighborhood point, facility point and transport network. The criteria for dwelling type classification is based on the standard from government website (BMCHURD, 2016). Only the living facilities necessary for human life were considered in this model such as shopping, restaurant, recreation, hospital and school. In fact, according to Beijing Transport Annual Report (BTRC, 2015), the above resilient activities account for 41.5 percent of daily trips, being secondary to the share of work trips (50%) in Beijing. The minimum distance between origin and destination along transport network was used as the impedance. Owing to the limitation of space, only short distance bins (i.e. 1km, 3km and 10km) were considered in this paper.

3 Case study

The model was applied in Beijing city to compare the low carbon potentials between work unit group and non-work unit group. For subsistence activities, the low carbon potential is characterized by the proportion of short distance work trips. For resilient activities, the Mixed Land-Use Index in short distance (1km and 3km respectively) was calculated in each neighborhood and averaged into different dwelling types. There are around 7832 neighborhoods in Beijing city, all of which were mapped into ArcGIS system. Based on the classification standard in Section 2.1, the geographical distribution of Work unit, State Apartment and Commercial Housing is presented in figure 4, figure 5 and figure 6 respectively. It can be seen from these graphs that the work units mainly lie in the city center(within loop 5), the amount of state apartment is much less than that of work unit and commercial housing, few state apartments situate within loop 2 and the commercial housing has somewhat similar distribution pattern as the work unit.

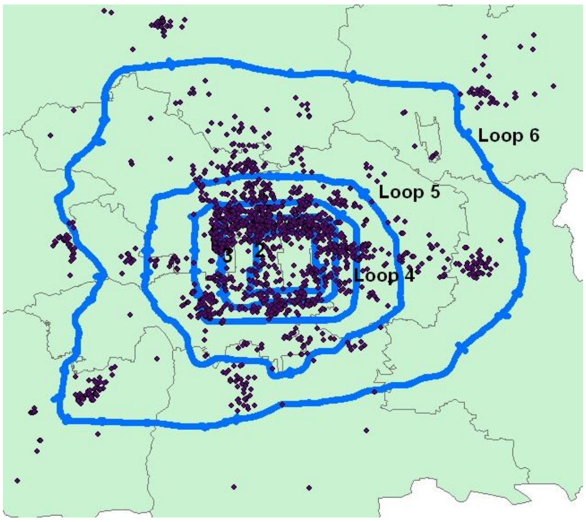


Figure 4. Work Unit distribution in Beijing

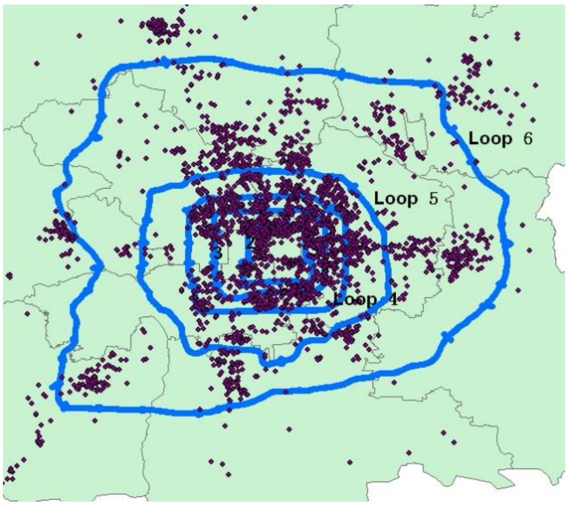
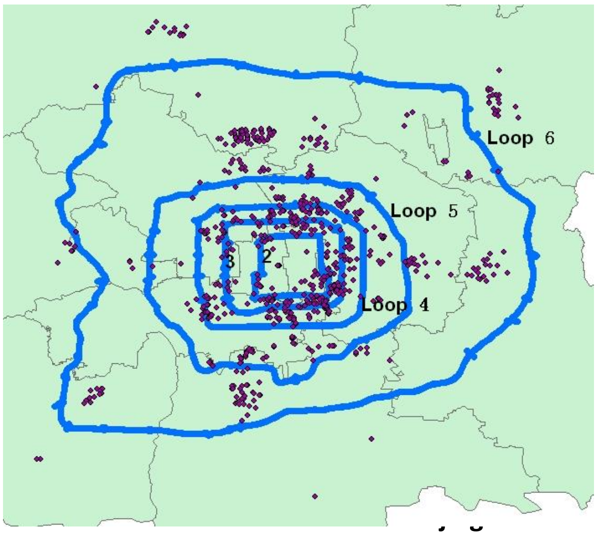


Figure 5. Commercial Housing distribution in Beijing



3.1 Subsistence activities

In light of the nature of work unit, it is obvious that the work unit design could contribute more to reduction in commuting distance. Based on the travel survey data of Beijing residents in 2007, Liu, Zhang & Chai (2009) made an investigation on commuter's travel patterns in different dwelling types and calculated the Euclid distance between their working places and living places. The comparison of commuting distance is shown in table 1. It can be seen that the work unit has significant advantages in short distance work trips, the average commuting distance for work unit is only 3.9km, nearly half of residents living in work unit could commute by walk or bicycle. Therefore the possibility of using motorized travel mode for commuting is supposed to be lower in work unit, which was testified by the research findings from Zhang and Chai (2009) (see Table 2). Around 70 percent of residents living in work unit go to work by walk or bike, whereas the commercial housing option might lead to higher car trip share. Accordingly, in terms of work trips, the work unit has obviously low carbon travel potentials in comparison with the non-work unit.

Table 1. Commuting distance comparison by dwelling type

Dwelling Type	Mean commuting distance(km)	50 percentile value (km)	Standard Deviation
Work Unit	3.9	1.3	5.6
Commercial Housing	7.2	5.4	7.6
State Apartment	10.1	9.6	8.5

Table 2. Travel mode split by dwelling type

Dwelling Type	Total trips	Travel mode split (%)		
		Walk and bike	Transit	Car
Work unit	8.11	67.43	18.75	13.83
State apartment	7.74	58.50	21.55	19.95
Commercial housing	7.14	52.70	23.75	23.55
Total	7.90	64.71	19.59	15.70

3.2 Resilient activities

After iterating all the living facility datasets (e.g. shopping point, restaurant point) within 1km and 3km, the matrix of Mixed Land-Use Index for each neighbourhood was obtained with the assistance of Service Area Tool in ArcGIS, a screenshot of which is exemplified in table 3. The matrix indicates that almost all the basic living requirement could be accessible within 1km in Beijing, the shopping facility has the largest share for Chinese spare life, followed by the restaurant facility. The variation of Complexity is not that conspicuous in each neighbourhood, however the Mixed Land-Use Index is dramatically different depending on the sum of living facilities around.

Table 3. A screenshot of the facility matrix in each neighbourhood within 1km travel distance

FID	Property	NShop_1km	CShop_1km	Nhos_1km	Chos_1km	Nrest_1km	Crest_1km	Nrecre_1km	Crecre_1km	Nedu_1km	Cedu_1km	Complexity	sum	Mixed
0	State Apartment	46	18	9	3	37	5	29	8	1	1	1.879554	122	229.305557
1	CommercialHousing	16	9	3	2	5	1	12	3	1	1	1.874749	37	69.365697
2	WorkUnit	44	18	6	3	24	3	32	6	1	1	1.827786	107	195.573101
3	CommercialHousing	18	12	0	0	10	3	9	5	2	1	1.726242	39	67.323431
4	WorkUnit	5	4	1	1	16	2	0	0	0	0	1.02263	22	22.497855
5	WorkUnit	109	33	8	3	123	13	56	11	1	1	1.679392	297	498.779528
6	State Apartment	58	19	8	3	25	3	38	6	1	1	1.797133	130	233.627268
7	CommercialHousing	6	4	2	2	3	3	0	0	0	0	1.435371	11	15.789085
8	CommercialHousing	92	24	5	2	116	11	42	12	2	1	1.64072	257	421.665042
9	CommercialHousing	48	18	4	2	41	6	42	8	2	1	1.81179	137	248.215231
10	CommercialHousing	127	27	7	3	74	11	49	9	2	1	1.669956	259	432.518575
11	CommercialHousing	38	15	10	4	28	2	22	6	0	0	1.8662	98	182.887605
12	WorkUnit	70	21	8	4	88	10	42	10	4	1	1.803594	212	382.362011
13	CommercialHousing	29	13	4	2	12	2	9	4	1	1	1.773536	55	97.54446
14	WorkUnit	215	33	5	2	172	13	80	10	3	1	1.59642	475	758.299483
15	CommercialHousing	51	19	4	3	29	5	20	7	3	1	1.794097	107	191.968377
16	CommercialHousing	100	31	5	3	106	13	47	11	1	1	1.645301	259	426.132843
17	WorkUnit	21	13	2	1	16	3	13	6	2	1	1.896658	54	102.419543
18	WorkUnit	116	29	7	3	119	8	69	10	1	1	1.691977	312	527.896711
19	CommercialHousing	119	29	10	5	58	8	59	7	2	1	1.734271	248	430.099253
20	WorkUnit	38	17	5	2	84	9	37	10	1	1	1.664896	165	274.707841
21	CommercialHousing	58	23	2	2	38	4	23	7	1	1	1.641999	122	200.323887
22	CommercialHousing	7	2	1	1	2	1	2	2	0	0	1.614005	12	19.368066
23	CommercialHousing	54	19	3	2	34	4	30	8	0	0	1.66515	121	201.483185

The geographical distribution of work unit and relating Mixed Land-Use Index within 1km travel distance was mapped with the interpolation tool of ArcGIS to visualize the aggregate characteristics of work unit at the city scale (figure 7). It is shown that apart from the city centre, some work units lying in outskirts or suburb area also have higher degree of mixed land use, which to some extent facilitate the diversity of regional lifestyle and consequently reduce the possibility of long distance resilient trips to the city centre.

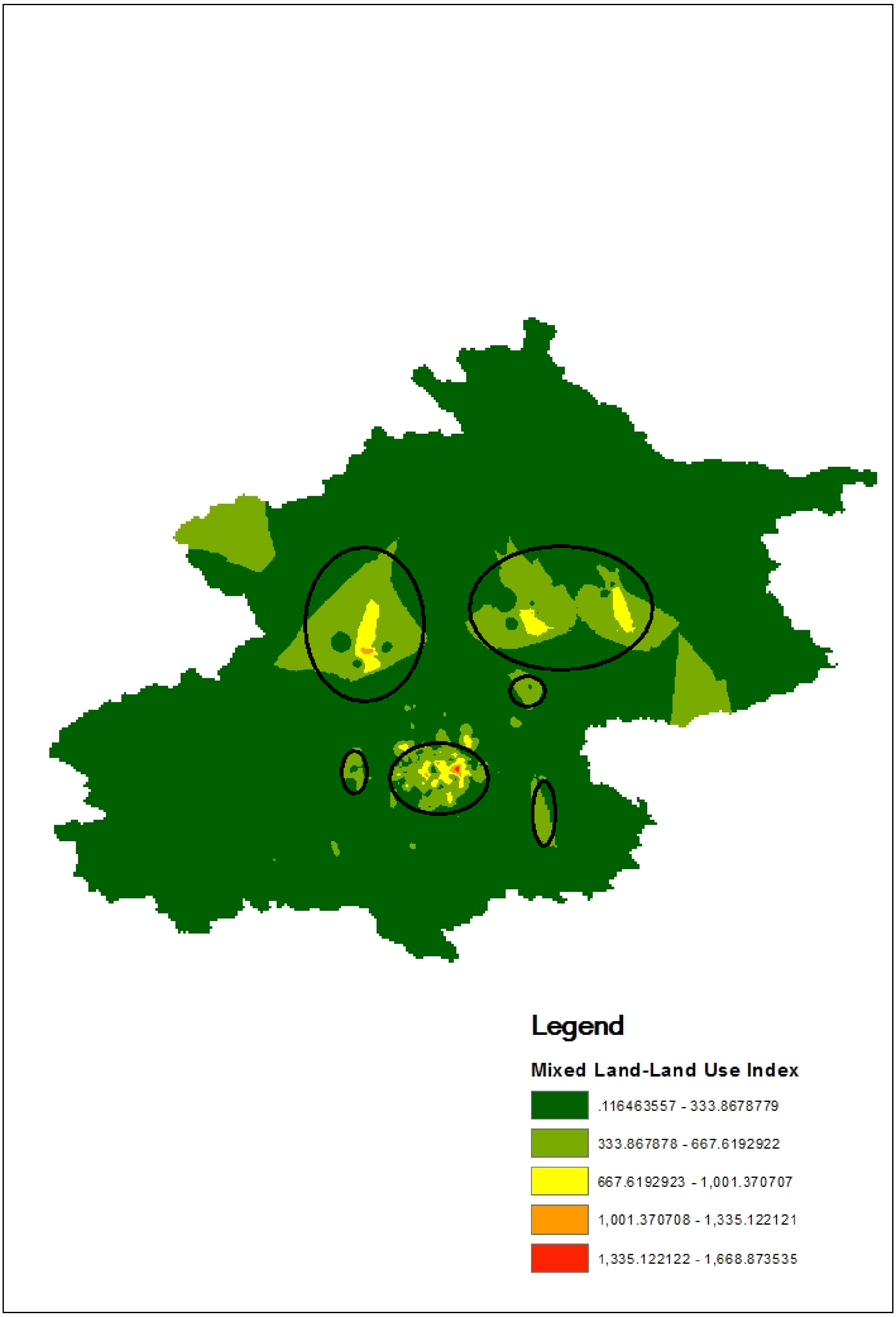


Figure 7. Geographical distribution of Mixed Land-Use Index of the work unit in Beijing (within 1km)

The changes in the quantity of different kind of facilities within 1km and 3km are shown in figure 8 and figure 9 respectively. With the increase of travel distance, the amount of shopping facilities grows sharply from about 100 to nearly 1000 and no much variation in the number of restaurant and recreation facilities between 1km and 3km, the number of hospital has a small range of growth from about 10 to nearly 100. However in terms of average accessibility in each category, there is no much difference between work unit group and non-work unit group, which indicates that the non-work unit still follows the way of work unit in the layout of living facilities. On average, the commercial housing option is the best in accessing all kinds of living facilities within walkable distance (1km), whereas the work unit has a slightly higher value in satisfying people’s diversified requirement within cycling distance (3km). In the sense of geographical distribution, the degree of diversification is not consistent in Beijing, with the city centre area being of the highest value.

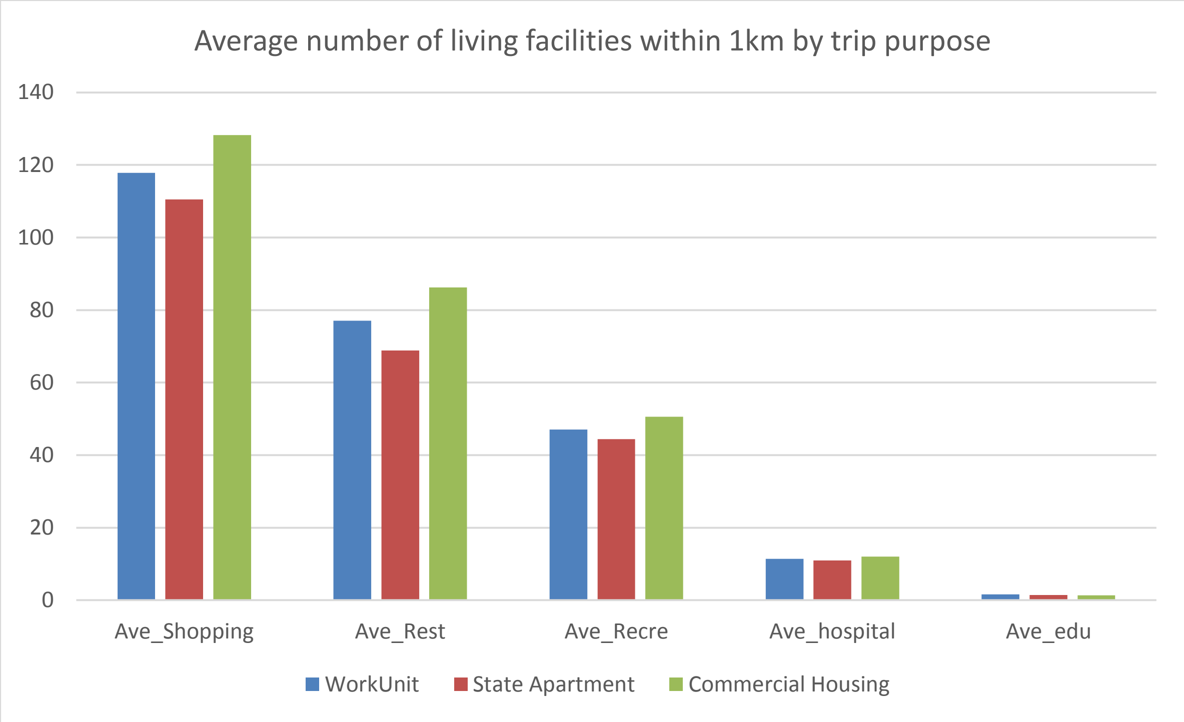


Figure 8. Comparison of accessibility to living facilities within 1km

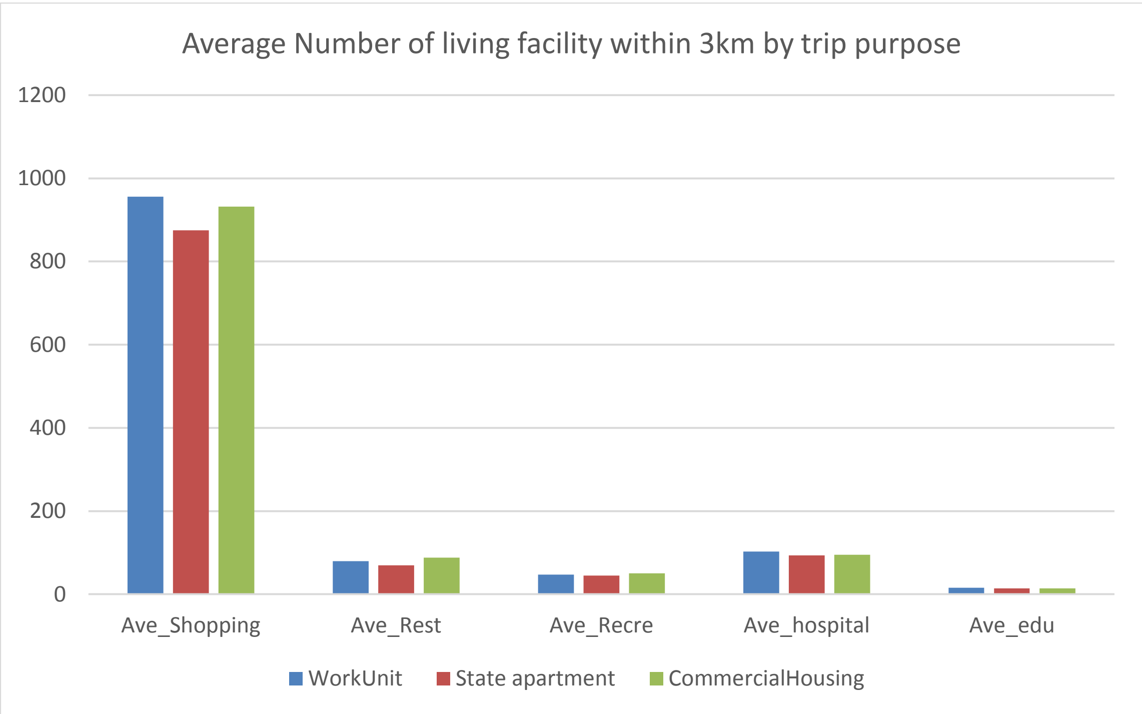


Figure 9. Comparison of accessibility to living facilities within 3km

The imbalance in the proportion of different kind of facilities results in the fluctuation of complexity value in different distance bins (see figure 10). The average complexity of facility distribution in walkable distance of Beijing is essentially identical no matter what kind of dwelling type it is, it has been guaranteed by government that at least one option in each kind of living facilities could be accessible nearby. Nevertheless the value of Mixed Land-Use has gradually grown with the distance increment, the state apartment option being the lowest in each distance bin. There is only a marginal difference between work unit and commercial housing, which might result from the similar geographical distribution pattern (see Figure 4 & Figure 5).It can be inferred from Figure 11 that the potential to further destinations would presumably be going up with the increased value of Mixed Land-Use Index.

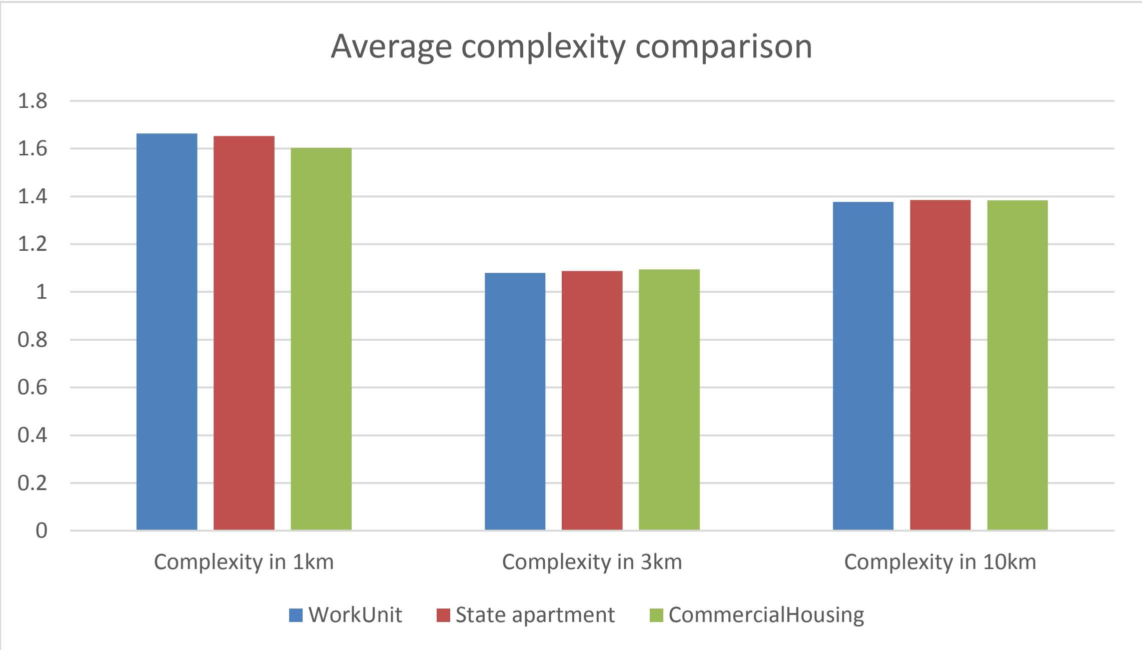


Figure 10. Variation of Complexity in different distance bins

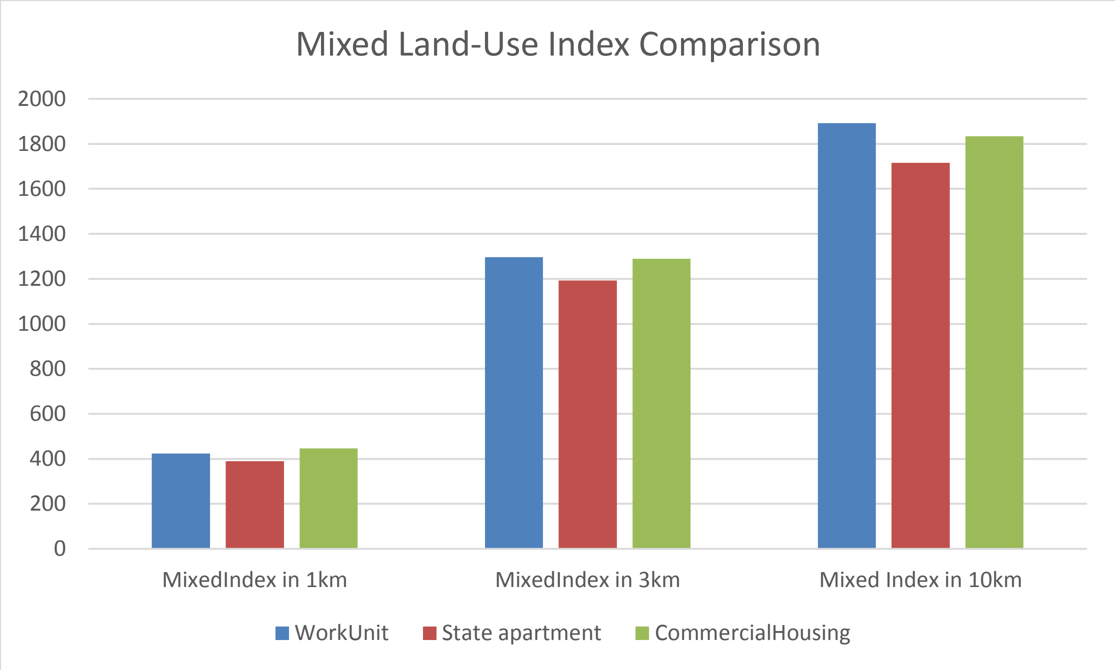


Figure 11. Variation of Mixed Land-Use Index in different distance bins

The aggregate result of Mixed Land-Use Index at the precinct scale in Beijing was calculated by taking the average value of each neighbourhood, in comparison with the number of work unit per precinct (Figure 12). It can be seen that the higher quantity of work unit contributes to higher mixed land use index at the precinct scale. Besides the city centre, where the conventional work unit areas were centralized, a few precincts (see the black circled areas) in the periphery of Beijing city also have good results of diversified amenities. Therefore, it is foreseeable that for the suburb areas, the work unit design with the coexistence of inhabitation and employment could reduce the possibility of long distance trips that otherwise would have been accomplished by entering into the city centre, furthermore the all-embracing design pattern of work unit facilitate mixed land use development as well.

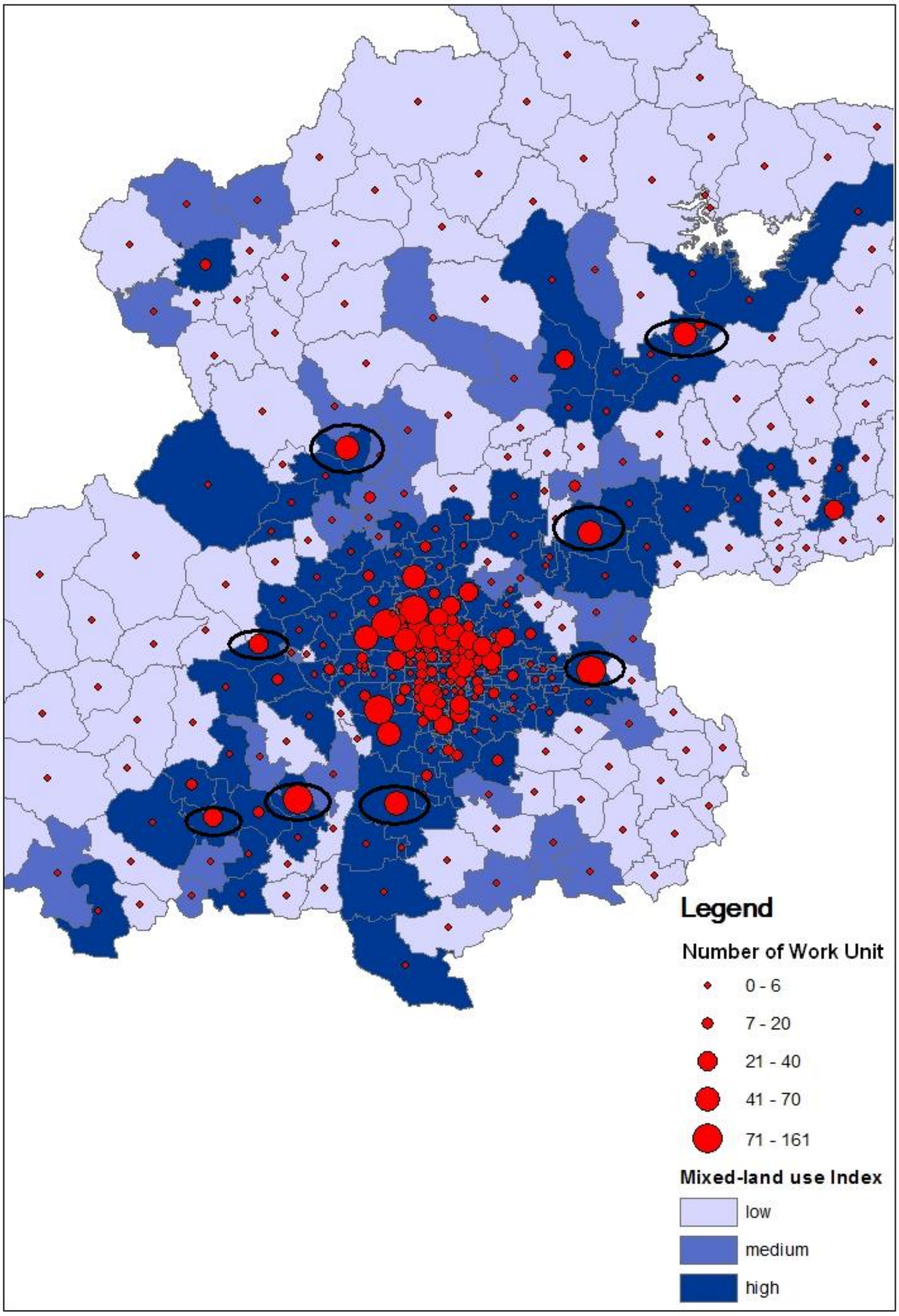


Figure 12. Number of Work Unit vs. Mixed Land Use Index

It is undoubted that China will grow into a powerful economy affecting world energy outlook in the next decades. Nonetheless the risk of oil supply-demand disparity in China and the resultant problems of extensive development relying on high energy consumption would be severe obstacles for China to overcome. Apart from technical progress, the enhancement on efficient use of public space and the reduction on private car use should be highlighted during the course of Chinese city planning and land conversion in the long run. In the aspect of high density development and jobs-housing balance, the conventional work unit design provides a good approach to realizing low carbon travel and meeting diversified living requirements.

After a brief introduction about the history and characteristic of work unit, this research presents a quantitative model to characterize human daily transportation activities. For subsistence activities, the significant advantage of work unit in reducing commuting distance is illustrated by analysing the travel survey data in Beijing. For resilient activities, a new metric of Mixed Land-Use Index, defined as the production of Accessibility and Complexity, is introduced to represent the degree of mixed land use in short distance bins. Based on these metrics, the comparative analysis between work unit group and non-work unit group was implemented to show the relative merits of work unit. In the case of Beijing city, the work unit neighbourhood has a slightly higher value in accessing various living facilities by walk and cycling with different geographical distribution at the city level. This model also provides a good perspective to compare the proportion of all kinds of living facilities. The research findings show that the shopping activity plays a critical role in Beijing’s non-work trips, which results in the decreased complexity between walkable distance and cyclable distance. Besides the good result in the city centre, the work unit pattern was also found in suburb areas of Beijing with relatively higher value in Mixed Land-Use Index. For regional development, the work unit design could improve local Mixed Land-Use Index, which is testified by the aggregate analysis of precinct in Beijing.

Although the work unit is now losing its dominance in Chinese urban form transformation, its perception on compact design and complete function for basic necessities still offer a good foundation for low carbon or sustainable development. The comparison between work unit group and non-work unit group shows that the high density development pattern oriented from work unit design still has a profound impact on other dwelling types. It would be more likely to enhance overall low carbon potentials by realizing more localized employment when it comes to residential community development.

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2.3 **Commuting distance and transport energy resilience**: quantifying human commuting distribution to explore low carbon potentials with transition projects

Abstract

Human commuting activity plays a significant role in understanding urban transport systems. This paper proposes a novel approach to modelling commuting distance distribution in a concise way. Having studied a small number of training data in New Zealand, it is found that the human commuting distance distribution can be quantified as a simple CDF exponential function with only one parameter to be determined, and the parameter is mainly dependent on the average distance to employment catchment. Besides its good predictability for test data, a Monte Carlo method to calculate the commuting VKT was introduced in the course of validation with considerable approximation to the real VKT observation. Two case studies on how to apply this model are presented to manifest its strength in exploring low carbon potentials in urban transport system, assuming that commuters could cycle to their workplaces in short distance, and an efficient commuting bus line was developed to replace the car driving in long distance. This model is convenient in simulating and predicting commuting distance distribution with limited data availability, and provides a quantitative foundation for analyzing urban transport resilience and emission mitigation.

0 Introduction

Predicting human mobility has been an essential subject in various research fields including transportation, geography, business and epidemiology (Barthélemy, 2011;Batty, 2008). A body of research have been carried out to unravel the nature of human trajectories and locations thanks to the emergence of big-data and the improvement in technology. A study by (Gonzalez, Hidalgo, & Barabasi, 2008) argues that the distribution of human displacements is well approximated by a power-low as bellows:

$$P(\Delta r) = (\Delta r + \Delta r_0)^{-\beta} \exp(-\Delta r/\kappa) \quad (1)$$

with exponent β=1.75$\pm$0.15 and $\Delta r_0 = 1.5$ km. The research findings indicate that the travel patterns of human beings could be quantified as a spatial probability distribution, the highest probability occurring in a few frequently visited locations. Shi et al.(2008) also employed probability theory and statistics under some hypothesis conditions to simulate residential trip distribution, it was found that the Rayleigh distribution function has a similar pattern with the residential trip distance distribution. Yan, Zhao, Fan, Di, & Wang(2014) proposed a population-weighted opportunities model without any parameters to represent the underlying mechanism that presumably affect human mobility patterns at the city scale. It is found that this model has a good predictability for distance distribution, destination travel constraints and travel flows.

Commuting trip plays a significant role in human mobility, which is highly reliant on motorized travel mode in high-income countries((Poumanyvong, Kaneko, & Dhakal, 2012). The continuous increase in the commuting distance has been a challenging problem for urban smart growth and sustainable development. In developed countries like France, the average distance from home to work has grown by 16 percent over the last decade((Aguilera, 2005). According to OECD(2005), commuting distance has increased in the OECD countries with 1%-16% employees commuting between regions every day. In the case of New Zealand, most commuters do not travel very far to their workplaces, with nearly 47 percent travelling less than 5km and 67 percent travelling less than 10 km (NZ statistics, 2015). However little attention has been paid to the study of commuting distance distribution, say what percentage of OD trips are within walkable and cycleable distances and how are commute distances correlate with urban form and land use characteristics.

How to model commute activity remains an important issue for planners and policy-makers. Gargiulo, Lenormand, Huet, & Espinosa(2011)proposed a commuting network model with only one parameter based on the conventional gravity law governing commuter's choice for workplace location. An individual-based approach was established by Lenormand,et al.(2012) to overcome the difficulty of doubly-constrained gravity model when no complete matrix of the commuting flows available. It is found that the single parameter of this model follows a universal law that is mainly dependent on the surface area of the geographic units. Although these models have some strengths in simulating commuting network, the detailed data on the amount of commuting in and out of a study region are still required for the calibration of parameter. Prior to urban planning or transport project, the travel survey is a pragmatic method to capture the location, distribution and mobility decision, even sometimes the socio-economic situation and personal characteristics are necessary for calibration, which are costly and time-consuming(Michael,2004).

This research was motivated by the need to mathematically characterize the commuting activity in terms of distance-resolved distribution to explore the potential of emissions mitigation in a city. By analyzing a handful of sample travel survey data, it was found that the commuting distance in New Zealand also follows an exponential law and the single parameter has close correlation with the spatial structure of residence and employment. This paper can be divided into three parts. The first part is the model development with the aim to discover a universal law governing commuting distance distribution. The dataset on commuter's trip distribution in Christchurch city was first analyzed with the attempt to develop a distance-resolved commute distribution function. Then the calibration of parameter and associated influencing factors were investigated to express the model in a concise way. The second part is the validation analysis to testify the predictability of developed model for test data and VKT data, in which a Monte Carlo method to estimate individual commuting trip assignment were proposed in comparison with real VKT data. The final part is the application and case studies of the developed model in hypothesized transition projects. Assuming that commuters may minimize car driving in accordance with different distance bins, two scenarios were proposed to explore low energy-intensity potentials when car trips are forgone.

1 Model

1.1 Data source and explanation

Commuter flows. All the studied data are drawn from the commuters travel survey by Statistics New Zealand (Statistics New Zealand, 2013). All the information about a commuting OD pair including travel distance, means of travel, number of commuters can be obtained from this database. In this research, the model development was mainly carried out on the analysis for Christchurch city, from which 20 census tracts were randomly selected as the training data to perform model development, and other 15 census tracts were randomly selected as the test data to validate the predictability of the developed model. In addition, the dataset of Dunedin and Waikato were also analyzed to evaluate the universality of proposed approaches.

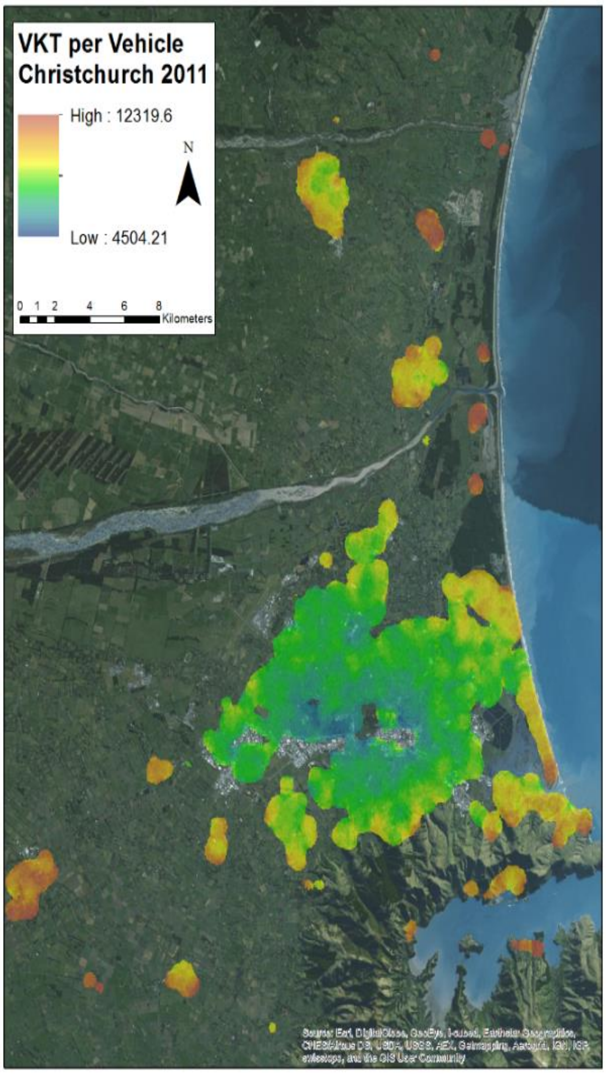


Figure 2-7. Local average VKT/Vehicle interpolation of Christchurch, 2011.

VKT data: In New Zealand, all the road-going vehicles are required to have regular inspections for safety (warranty of fitness, WOF). During this inspection the reading on the vehicles odometer is recorded (i.e. Vehicle Kilometer Travelled), along with the registered address and information of fuel type and engine size. Based on the available VKT database, the average annual VKT per vehicle at the census unit level has been calculated by AEMS Lab(Rendall, Page, & Krumdieck, 2015). An example of VKT distribution in Christchurch is shown in figure 1 to illustrate how VKTs geographically differ at the census unit level.

1.2 Data mining

Distance grouping. The distance and number of commuters to destination zones from an origin zone can be obtained from the sample training data. In order to explore the underlying laws governing distance distribution, all the OD distances were grouped into consecutive distance bins based on interval of 1000m, and then the number of commuters in each distance bin were summed up. Thus the quantity of commuting trips in different distance bins was obtained, then the relative probability of commuter's distance-based distribution and the cumulative probability can be depicted using Origin Software. The distribution of PDF and CDF of Riccarton area and Hornby area in Christchurch are exemplified in figure 2 and figure 3 respectively.

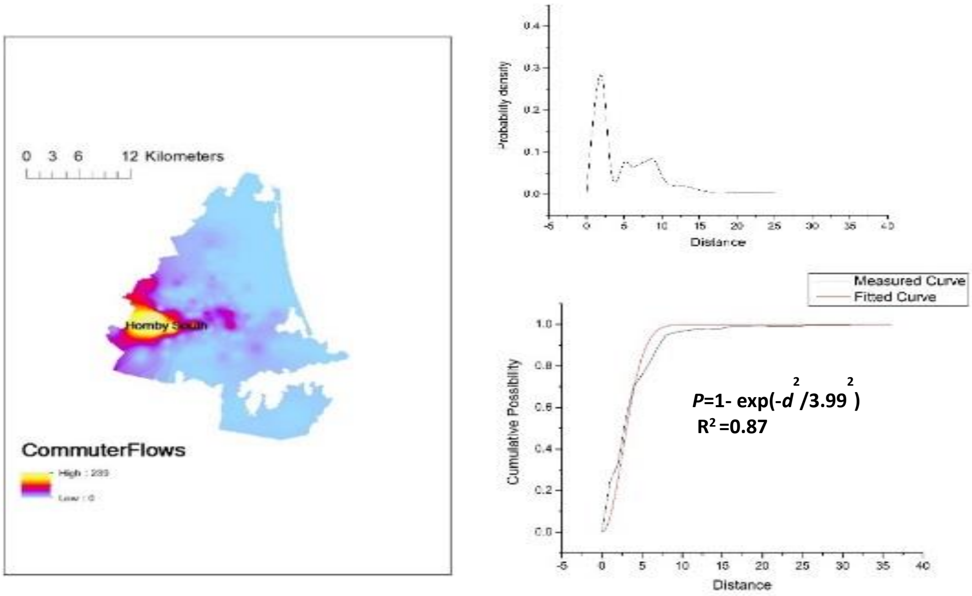


Figure 3 Distribution of Commuter flows from Hornby North region

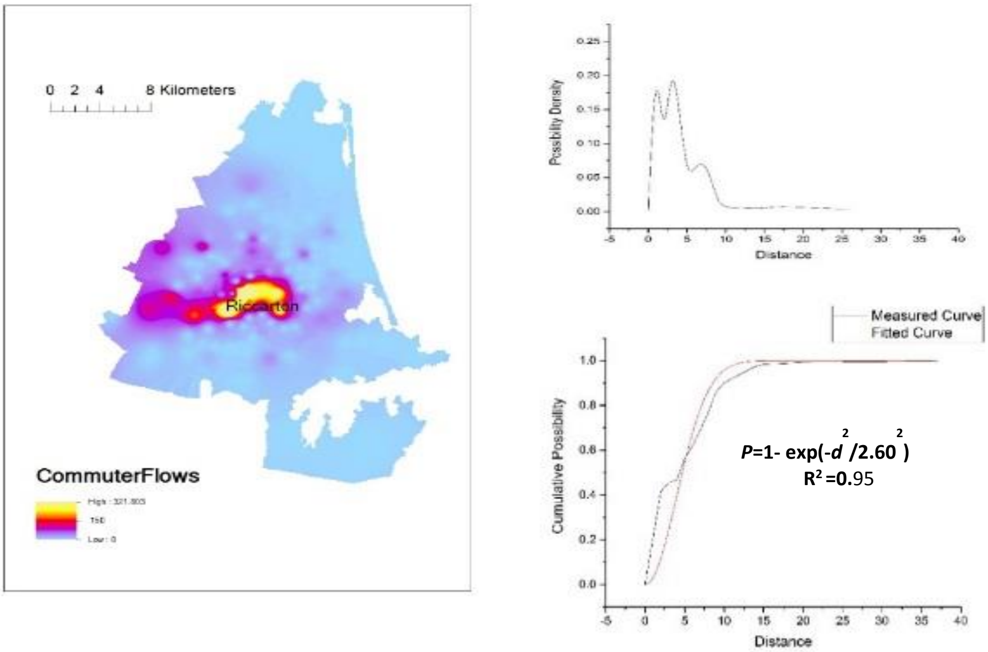


Figure 2 Distribution of commuter

Curve fitting. As for the relative possibility density distribution, it looks like a multiple peak distribution, which is difficult to fit with an explicit mathematical function. The cumulative density curve, by contrast, exhibits a goodness of regularity and can be fitted with a statistics function (see figure 2 and 3). After a number of fitting trials for different regions, it was revealed that the exponential function family (e.g. Gamma, Rayleigh and simple exponential) best fit the cumulative possibility distribution (R^2>85%). Whereas the Gamma function takes a complicated form with two parameters to be determined, the Rayleigh CDF function was employed in this paper to represent the commuting distance distribution owing to its simple form with only one parameter to be determined(see equation (2)).

$$F(d) = 1 - \exp(-d^2/2b^2) \quad (2)$$

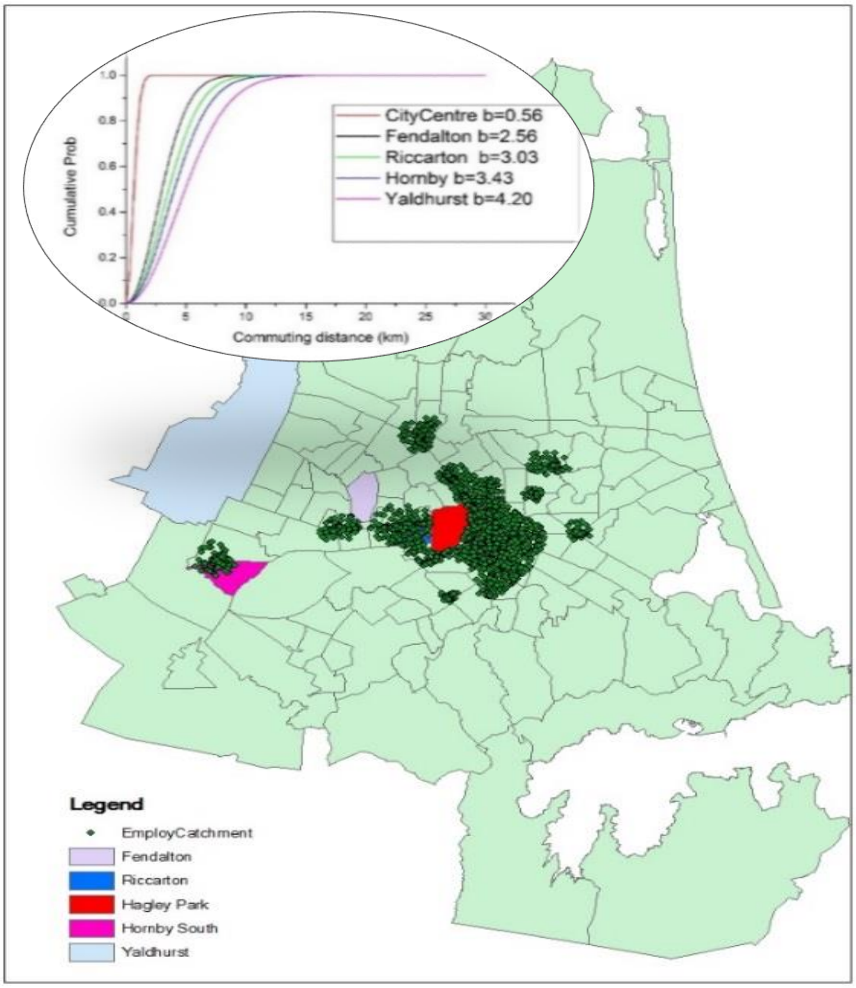


Figure 4 Variation of parameter in different census tracts

A series of simulated curves for some census tracts are exemplified in Fig 4, it can be seen that the degrees of skewness of curves are varying with different regions, indicating that each origin zone generate distinctive commuting distance distribution. Unsurprisingly, the city center has a higher proportion (nearly 90%) in short distance (<5km) than other areas. Therefore, it was proposed that the parameter could be used as a characteristic value to quantify the spatial distribution of commuters from an origin region. Given the value of parameter, the proportion of commuters within a certain distance interval can be calculated following the law of Rayleigh distribution. The next section analyze a few tangible factors that might influence the value of parameter.

Parameter analysis. First, 20 census tracts were randomly selected as the training data (see table 1), with regional attributes such as residents population, employment opportunity, number of workplace being considered. A number of studies (Van Acker & Witlox, 2011; Rouwendal & van der Vlist, 2005)suggested that the commuting activity is a multi-dimensional complex system influenced by a wide range of factors such as land use, demography, economic situation, and personal preference. Some variables with measurable dimension, for example, the distance and population are easy to obtain, while other subjective factors such as previous experience of long-distance commuting and the economic incentives (e.g. higher income) that are positively related to commuting distance(Sandow & Westin, 2010), are difficult to obtain or quantify. To avoid the effect of subjective factors, a couple of easy-to-capture variables such as the average distance to all employment facilities in a city, local population and employment opportunity as well as the number of workplaces in each origin zone were adopted as the explanatory variables to analyze their relationship with the value of parameter. Besides, according to Salze et al. (2011), the distance to major urban poles plays a significant role in affecting commuters spatial accessibility to facilities on the regional scale. Therefore the average distance to the key employment places were also included into the above explanatory variables. The information on the major job markets (i.e. employment catchment) can be either obtained from official data, or be identified by the combination of workplace location with associated job opportunities (see figure 4).

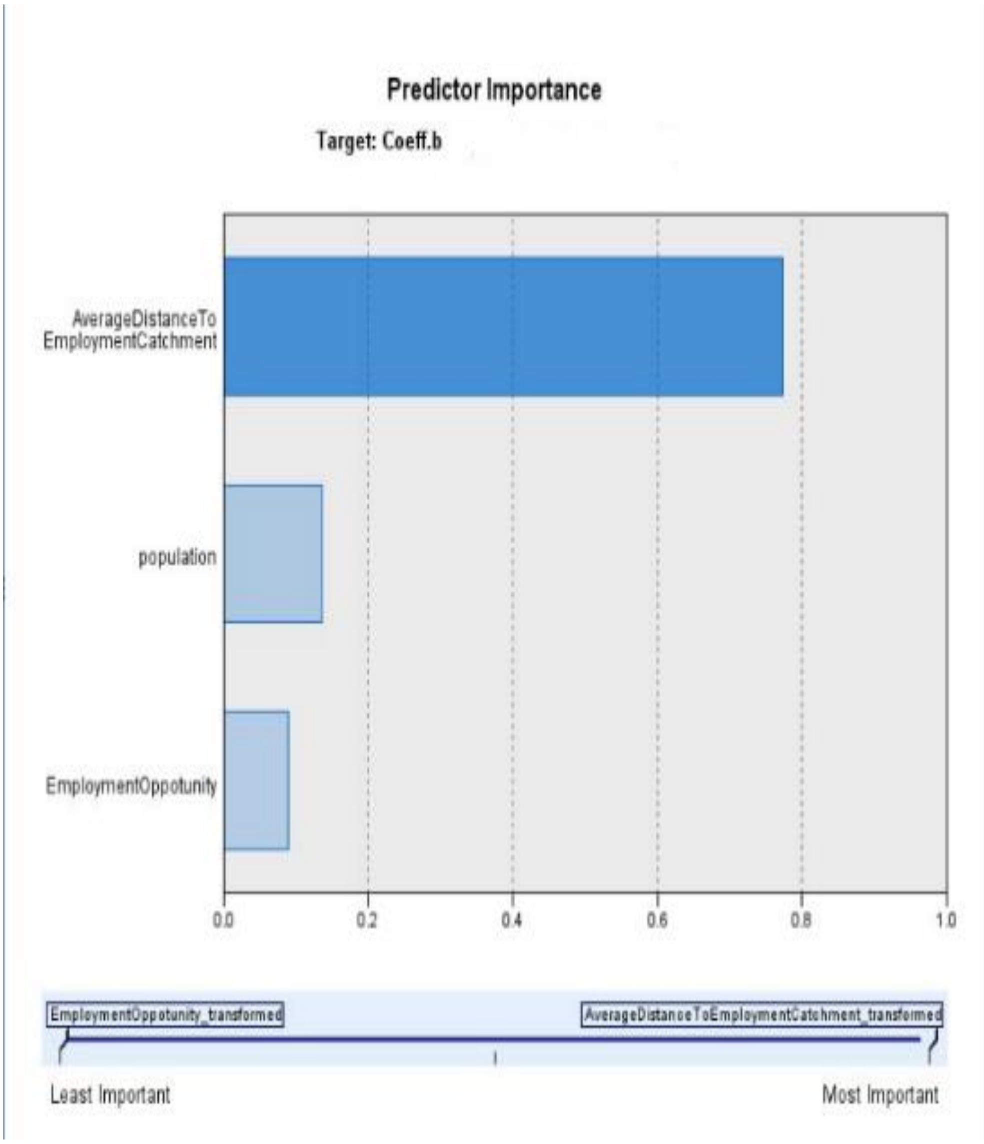


Figure 5 Correlation analysis between explanatory variables and the parameter

It was revealed by SPSS statistics analyst that only three predictors exert influences on the value of parameter, with the average distance to key employment places being the most significant sensitivity factor with nearly 80% incidence (see figure 5). Different from some previous conclusions(Levinson,1998;Schwanen, Dieleman, & Dijst, 2004), the accessibility to all workplaces, local population density and employment opportunity seem to contribute little to affecting commuting distance distribution. Accordingly, the average distance to employment catchment (i.e. the key employment places) was employed as the primary component in this paper to determine the value of parameter. The algorithm of computing average distances to each workplace point situated in employment catchment area is shown as below:

$$\overline{d} = \frac{1}{m \times n} \sum_{j=0}^{m} d_{ij} \qquad (3)$$

Where $\overline{d}$ is the arithmetical mean distance to each employment facility for origin household i, d_{ij} is the minimum network distance between origin *i* and workplace *j, m* is the total number of workplaces in the whole city, *n* is the number of household in the study region. For the sake of simplification, all the households in an origin zone can be aggregated into one point (e.g. the centroid of study region, see Figure 6) provided the study area is not very large. Thus equation (3) can be simplified as equation (4):

$$\overline{d} = \frac{1}{m} \sum_{j=0}^{m} d_{ij} \qquad (4)$$

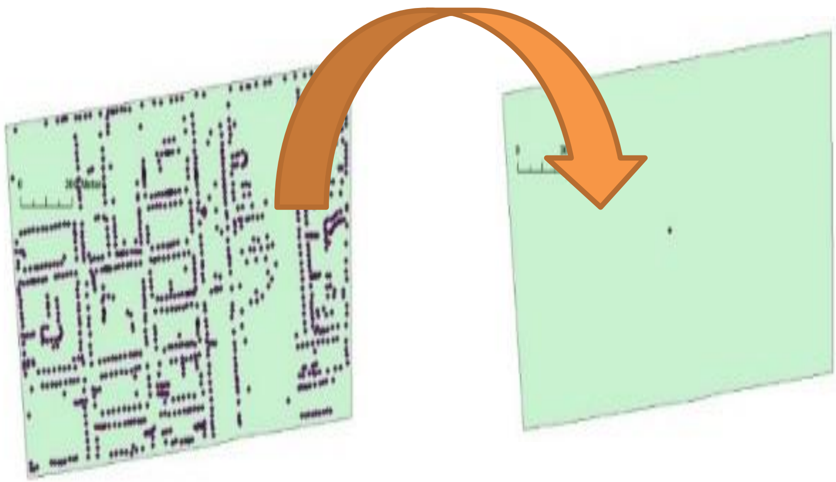


Figure 6 Simplification of Residence distribution in Riccarton

Table 1 Training data profile in Christchurch

Name of Census	**Parameter *b***	**Average distance to employment catchment** (km)
Hagley Park	1.068	3.952
Riccarton	2.6	3.839
Hornby North	3.42	7.709
Avonhead	3.32154	6.494
Hornby South	3.99	8.342
Ilam	2.9594	5.885
Burnside	3.396	6.819
Linwood East	4.03	6.943
Papanui	3.18669	5.224
Belfast	6.81583	11.654
Yaldhurst	4.199	9.816
Avondale	5.11165	9.292
Fendeltan	2.56227	4.975
Wigram	3.86598	6.843
Bishopdale	3.8072	6.584
Holmwood	1.88	4.464
Bromley	4.9964	9.679
Opawa	3.43882	6.698
St. Alban East	3.2086	4.567
Parklands	6.55716	11.718

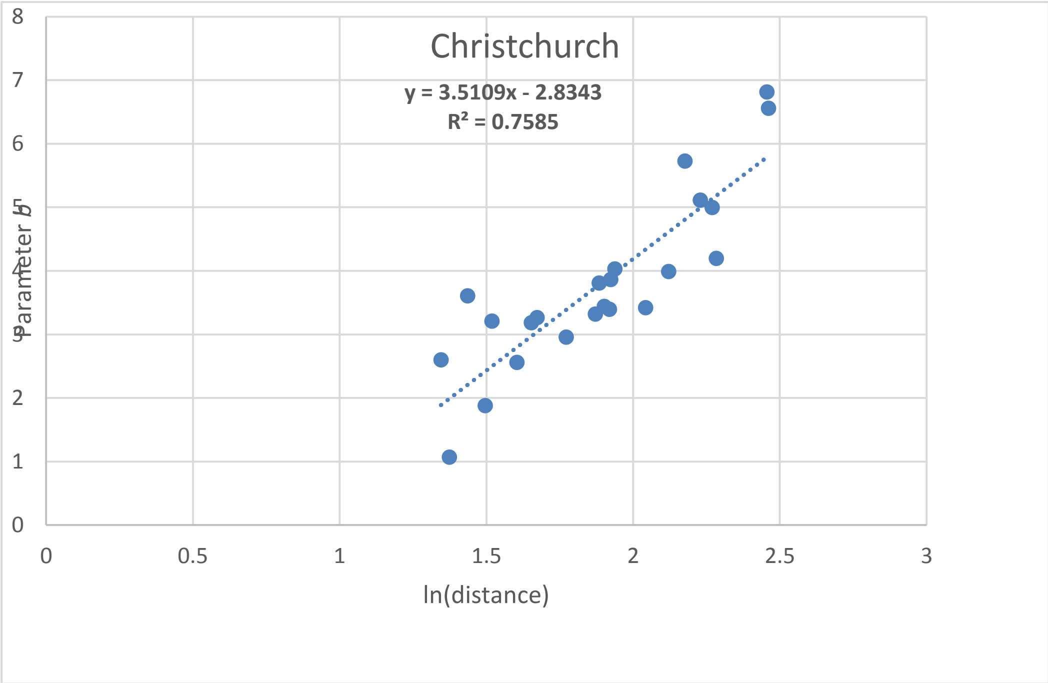


Figure 7. Parameter value as the function of average

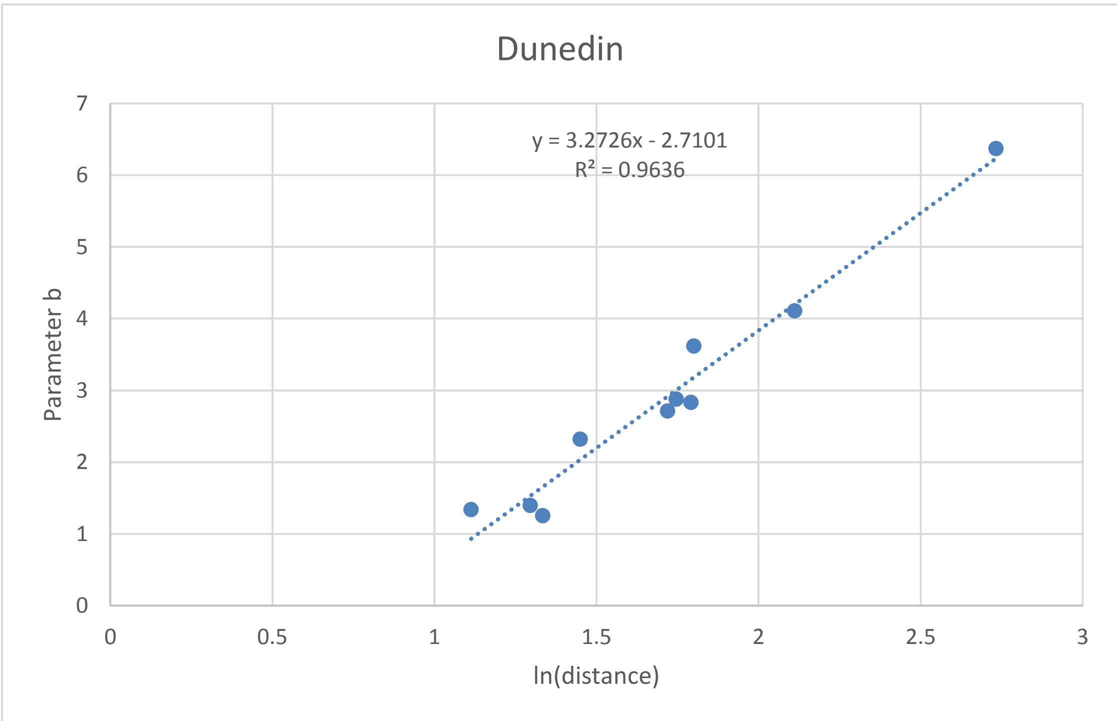


Figure 9. Regression result of sample census tracts in Dunedin

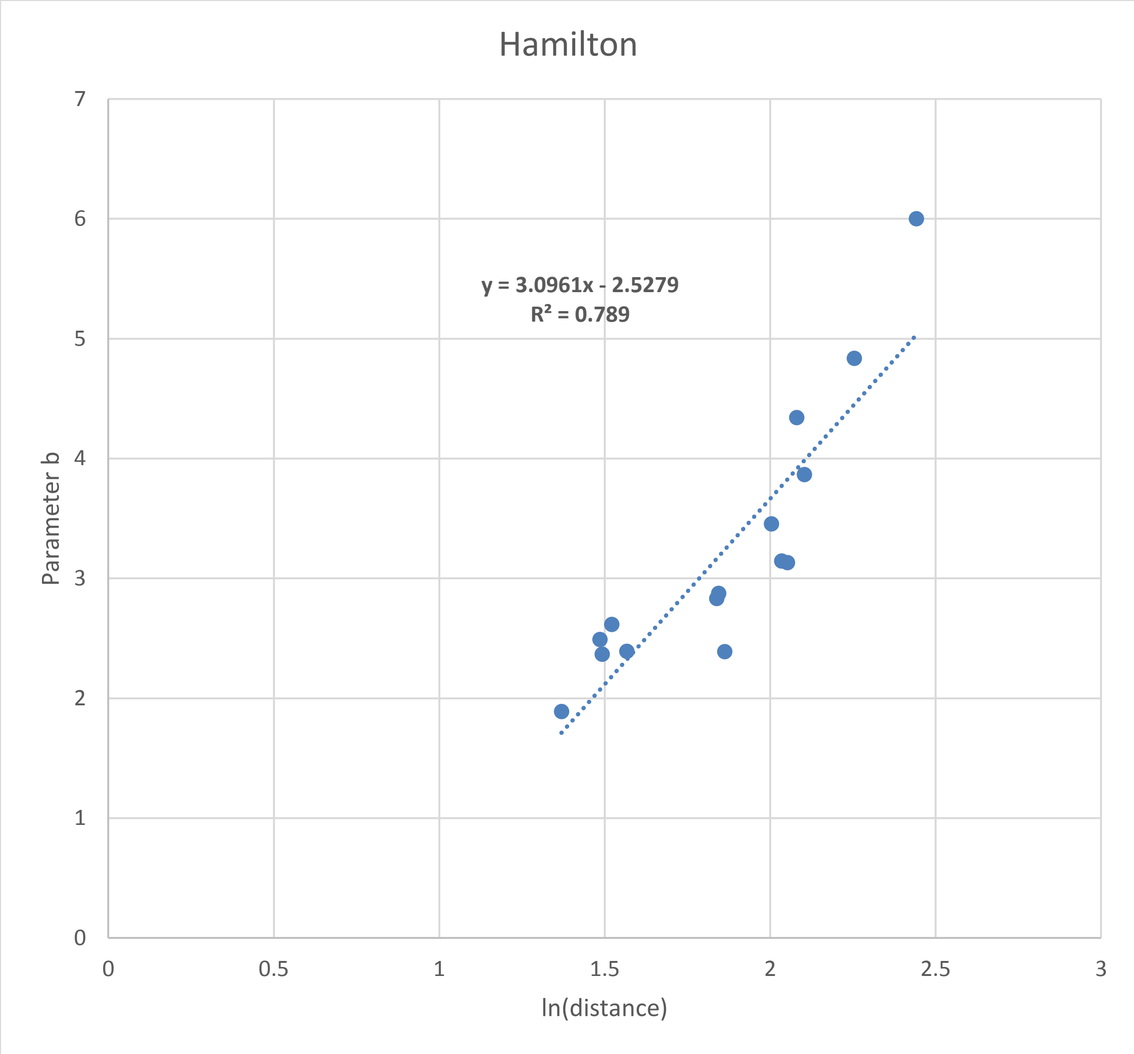


Figure 8. Regression result of sample census tracts in Hamilton

Each $\bar{d}$ of sample census was calculated and plotted as scattered diagram to illustrate the relationship between the parameter and distance, with the value of $\bar{d}$ being log-transformed to even out the variation distribution. It is found that the parameter has an approximately linear correlation with logged average distance to employment catchment (Figure 7). So it is safely to suppose that the value of parameter can be derived as the function of average distance to employment catchment, as shown in equation (5).

$$b = \alpha \ln(\overline{d}) + \beta \quad (5)$$ (**For Christchurch, α=3.5109, β=-2.8343**)

A tentative hypothesis was then formulated that the commuting distance distribution characteristic value (i.e. parameter) might be predicted by the geographic data only. In other words, given the spatial distribution of residents and employment in a city, the commuting distance distribution for each origin zone could be derived with limited sample travel survey. To testify this hypothesis, two types of data were utilized to validate the predictability of the developed model: one is the randomly selected 15 census tracts in Christchurch as the test data and the other one is the available VKT data.

2 Validation

2.1 Prediction for test data

The average distance to employment catchment for other 15 census tracts located from city center to suburb area have been calculated with ArcGIS system and then substituted into equation (5) to obtain the value of parameter. Then the cumulative possibility distribution curve of commuting distance for each census tract was fitted with Rayleigh function respectively. The comparison between observed parameter and predicted parameter is tabulated as below (table 2). It can be seen that majority of results are within acceptable error range (<20%) except for Kennedy's Bush (This census is situated in outer suburb area with only 735 population). Similarly the aforementioned approaches were applied to other two cities, Dunedin and Hamilton, to investigate whether commuters in New Zealand follow this universal law in terms of commuting distance distribution. The research findings support that the commuting distance distribution in these two cities can also be fitted with exponential function and the parameter can be derived from linear regression with good prediction(see figure 8 and 9). The value of α, β in different city are subjected to city characteristics, fluctuating around 3 and 2 respectively(see table 3). Much more calibration work need to be carried on for other cities to acquire the detailed value matrix of α, β in New Zealand.

Name of census	Observed parameter	Average distance to employment catchment (km)	Predicted parameter	Relative error (%)
Bexley	5.69054	10.04	5.26386159	7.5
Avonside	3.79005	6.539	3.758412718	0.83
Merivale	2.18	4.109	2.127232573	2.42
Beckenham	3.10615	6.232	3.589584281	-15.56
Aidanfield	3.81013	7.54	4.258498059	-11.77
Burwood	4.29927	8.117	4.517386368	-5.07
Northcote	4.02	6.262	3.606444726	10.29
Harewood	4.11514	8.11	4.514357305	-9.7
Spreydon	2.82	4.595	2.519712805	10.65
Sockburn	3.3204	6.717	3.852706286	-16.03
Dallington	4.028189	5.968	3.437613409	14.66
Richmond North	3.46776	4.866	2.720899623	21.54
Broomfield	4.26	8.858	4.824099918	-13.24
Travis Wetland	5.81744	9.175	4.947548037	14.95
Kenneydys Bush	4.55	13.283	6.246590264	-37.29
Lyttelton	6.2618	15.828	6.86203524	-9.59

Table 2. Prediction results for test data in Christchurch

City	α	β
Christchurch	**3.5109**	**-2.8343**
Hamilton	**3.0961**	**-2.5279**
Dunedin	**3.2726**	**-2.7101**

Table 3. The values of α, β in different cities

2.2 VKT validation

This possibility model is mainly focused on a quantitative measure to estimate cumulative distance-based distribution without involving directional analysis, nevertheless the detailed inter-region flows can't be derived from this model immediately. As mentioned in section 1.2, it is quite hard to quantify possibility density distribution of commuting distance. In the absence of data availability, Monte Carlo simulation is an effective approach to approximate the detailed situation about individual commuting trips. The next sections demonstrate the strength of this model in predicting commuting VKT trip distribution in comparison with existing VKT data if no individual home-to-work data available.

2.2.1 Individual-level commuting model

Most of commuting data were only available at an aggregated level, the disaggregated data on the specific location of household and workplace for each individual commuter has been lacking due to confidentiality reasons. Based on the travel survey data, Hu & Wang (2015) established a Monte Carlo methodology to simulate individual resident workers and individual jobs within census tracts to estimate the excessive commuting and optimal commuting respectively, in which the commuting time was used as the impedance for work trip model. In fact the travel distance is an effective variable to measure travel demand since it is easy to be converted into transport energy consumption(Becken & Schiff, 2010). Thus applying Monte Carlo methods with the assistance of ArcGIS techniques and Python programming, a distance-based disaggregated commuting model was developed to simulate the actual work trips distribution.

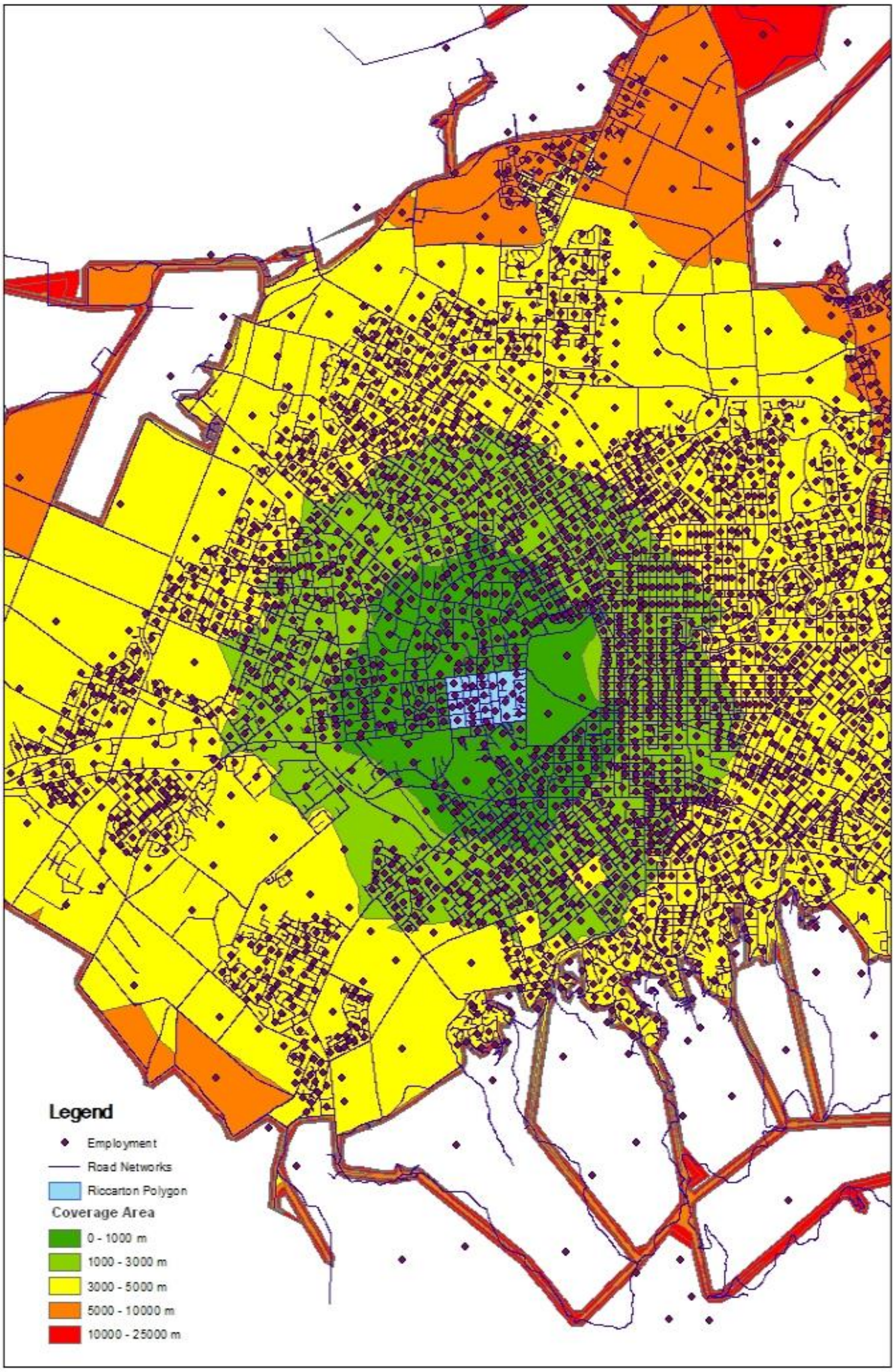


Figure 10. Employment facilities distribution in different distance buffer areas

Study area inputs

- Demographic data: the population of resident living in an origin census.
- Origins: It would be better to iterate all the households in the origin area, but in order to simplify the calculation, each centroid of origin census is regarded as the origin representing local dwelling distribution.
- Destinations: all the employment facility points were mapped into the GIS system.
- Transport networks: the travel impedance in this paper is defined by travel distance. Congestion and trip chains are neglected.

Constant inputs

- Modal split: According to Statistics New Zealand (2013), the car transport remained the dominant travel mode for work trips. The car travel mode share for commuting in Christchurch is 84%.It is hypothesized in this paper that all the census tracts have the same travel mode split.
- Commuting distribution parameter: all the parameters of census tracts have been calculated based on equation (5).

Methodology

Step 1: For an origin census, the commuter distribution in different distance bins can be determined by inputting demography into equation (6). So the number of commuter working in different distance bins are calculated. In this paper, the distance of 1km, 3km, 5km, 10km and 25km were selected as the critical threshold value for distance bin assignment.

$$P_{cn}=P_i \times \eta \times (1-\exp(-d_n^2/2\lambda_i^2)) \; (d_n = 1\text{km}, 3\text{km}, 5\text{km}, 10\text{km}, 25\text{km} \ldots\ldots) \quad (6)$$

Where P_{cn} is the number of commuters within a certain distance bin d_n. η is the ratio of employed population in origin *i*, which can be obtained from demographic data.

Step 2: generate distance-based coverage areas of origin *i* where the employment facility points in different distance bins are included. An example of employment geographical distribution in different coverage areas is illustrated in figure 10.

Step 3: randomly select a workplace *j* in a coverage area for a commuter *k* living in origin *i* until the commuters limit in this coverage area is reached. Then all the OD distance pairs in a coverage area can be calculated by GIS.

Step 4: randomly assign a travel mode for each OD distance pair following the travel mode split (The travel mode assignment was implemented in Python script to ensure the overall statistics in line with the required travel mode split). If the travel mode is assigned as 'car', this OD pair is then recorded as a commuting VKT element.

Step 5: Average all the commuting VKT elements to get the aggregated VKT result for origin *i*.

Step 6: Repeat the above steps for numerous times until the result tends to stability. Figure 11 shows the steady convergence of simulated commuting VKT of Riccarton area after 1000 iterations.

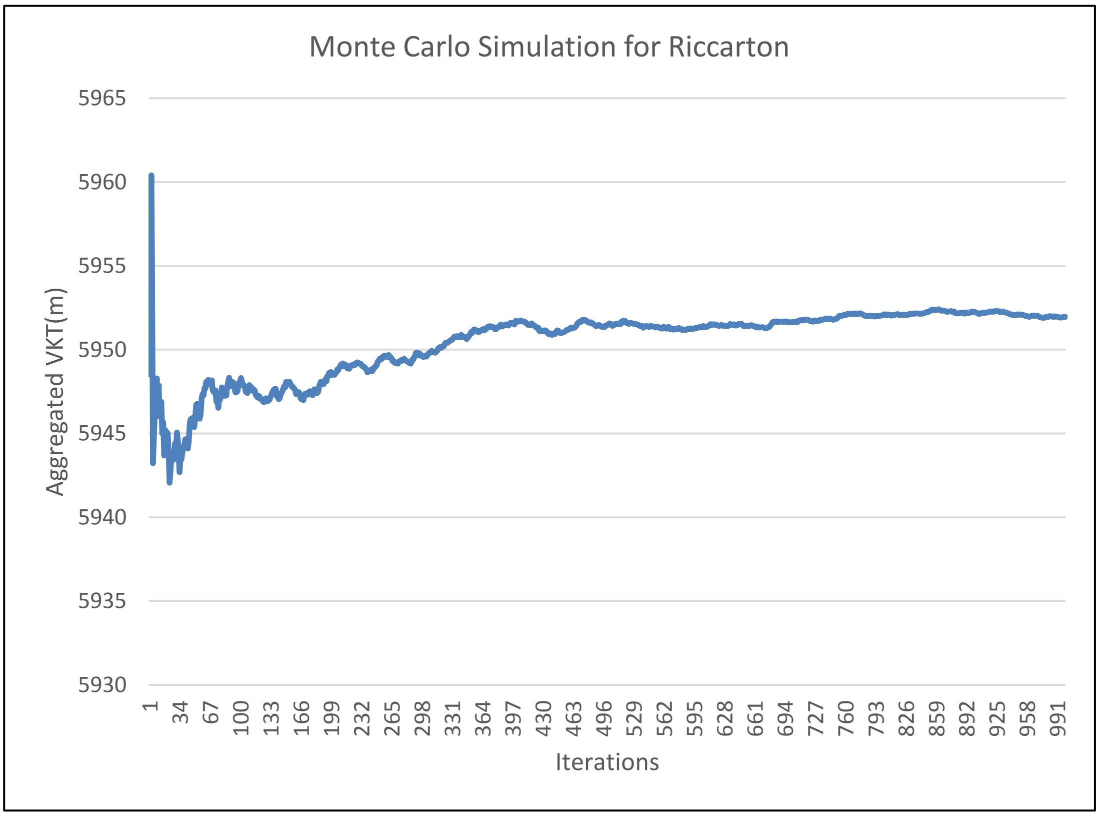


Figure 11. A change curve of accumulative average commuting VKT with iteration times

2.2.2 Real Commuting VKT extrapolation

Because the available VKT data is simply on the annual driving distance for individual registered vehicle, it is still in question to obtain the breakdown of VKT data for specific trip purpose at census unit level. Therefore some extrapolations based on literature reviews and travel survey were conducted to estimate the actual VKT data for commuting trips. According to MOT(2015), on average the work-related trip (travel to main job or other jobs and travel on employers business) accounts for about one third of all household driving time and distance. Accordingly with the obtained annual VKT per vehicle for each census tract (see figure1), the extrapolated one-way commuting VKT can be computed as follows:

$$VKT_c = (1/3 \times VKT_{avg})/250(workingdays)/2(back\ and\ forth) \quad (7)$$

The comparison between simulated Commuting data and observed commuting data was plotted in figure 12 to illustrate the variation trend with different census tracts. It is shown that both curves are almost parallel to each other, with slightly lower values in simulated commuting VKT data. The average relative error is no more than 20%, which supposedly result from the less rigorous computation in equation (7) or the homogeneous assumption for modal split of each census tract. It would be better to validate the developed model with realistic commuting data, nonetheless this model could be used as an alternative measure to estimate distance distribution in the absence of detailed travel survey.

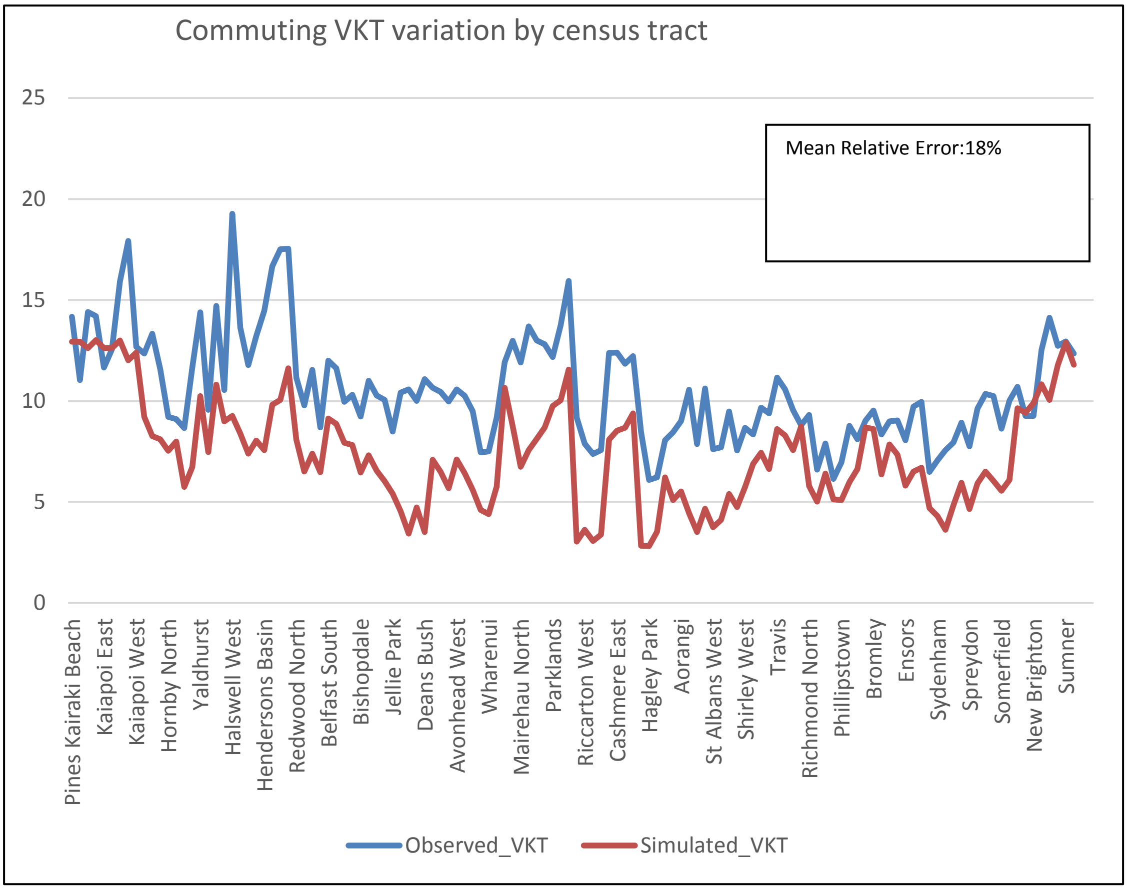


Figure 12. Comparison between simulated VKT and observed VKT in Christchurch

In summary, this model can be mathematically expressed in the following equations

$$\begin{cases} P_i = 1-\exp\left(-d^2/2\lambda_i^2\right) \\ \lambda_i = \alpha \ln\left(\bar{d}_{ij}\right) + \beta \end{cases} \qquad (8)$$

Where $\boldsymbol{P_i}$ is the proportion of commuters from origin *i* within a specified distance *d*, the value of λ is determined by the average distance to key employment places $\bar{d}$, which is calculated by d_{ij}. And d_{ij} is the distance from origin *i* to a workplace *j* in employment catchment. The employment catchment can either be obtained from official data (if any) or be depicted based on the integration of employment opportunity and distribution.

Application

This research has a positive significance for urban planning, transportation management and travel demand prediction. For instance, when it comes to urban resilience or active transport infrastructure, a pre-requisite problem is to learn about how many trips would be generated in different distance bins during urban development. For a particular area or planned area, it can be inferred from equation (8) that the less the $\overline{d_{ij}}$ is, the higher likelihood the short commuting distance occurs. As such this model provides a convenient tool for urban transport planners to assess how commuting distances vary with the layout of employment location or population migration. From the perspective of human beings adaptation to possible energy disruption, using techniques of ArcGIS system, the next section presents two transition projects applying the above model to explore low carbon commuting potentials in Christchurch, for which two scenarios were developed with the hypothesis **I**: Commuters can shift their car trips within short distance (<5km) into cycling or walking; and hypothesis **II**: a commuting shuttle bus line was developed to replace car trips in long distance. It is envisioned that commuters would minimize car trips to access their workplaces with alternative mode choices, but the land use and spatial structure remain unchanged.

Scenario 1: Cycleway investment site selection

It is assumed in this paper that the short distance car-driving to workplace would not be necessarily required if the cycling-friendly infrastructure were available and pro-bike policies were implemented. The threshold for viable cycling distance is defined as 5 km, and the average ratio of commuters of a census is set as 70% of local resident (Statistics New Zealand, 2013). Through calculating the average distance to employment catchment with the assistance of GIS network analyst, all the parameter values for each census tract have been obtained, then the population that could travel to their workplaces by walk or bike was computed according to the exponential distribution law as equation (9) exhibits.

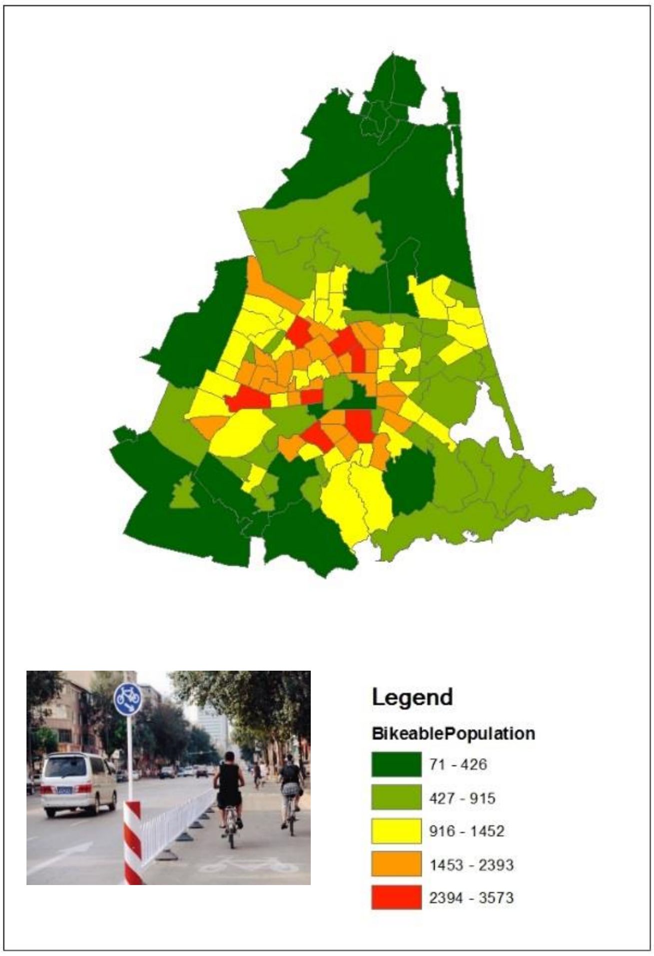


Figure 13. Ranking of Cycleable commuting areas in Christchurch

$$P_{ic}=P_i\times0.7\times(1-\exp(-5^2/2\lambda_i^2)) \qquad (9)$$

Where P_{ic} is the quantity of bikeable commuters potentially generated from origin *i*, P_i is the overall population in origin *i*, λ_i represents the characteristic value of commuting distance distribution for origin *i*. The distribution of people who could cycle to their workplaces was mapped in Figure 13, which shows the relative cycle-commuting potentials in different parts of Christchurch. Obviously the peripheral areas are less likely to adapt to cycling work trips due to the longer commuting distances, whereas living in close proximity to city center can contribute to reducing commuting distance. For dark red areas in figure 14, the possibility of cycling mode share might increase if the cycling infrastructure in these areas are improved with favorable policies (e.g. a physical segregation between cycle way and driving road, as shown in figure).

Scenario 2: Commuting shuttle bus line development

For long distance commutes, the only way to substitute car driving is the development of transit network system with high frequency services and wide coverage for residents. This model also has the strength to capture long-distance distribution, thereby facilitating the operation or optimization of public transport system. In the case of Christchurch, there is only one bus line (Orbiter route) operating with a high frequency service, and only 1 percent of people travelling to work by bus from surrounding districts(StatisticsNZ,2016). As a strategy to improve public transport and enhance environmental performance, a commuting shuttle bus line with regular service frequency was proposed using this model to meet resident's long-distance commuting demand.

Apart from the key employment places, the demand points where commuters have long distance work trips also need to be identified. This model can facilitate finding out these demand points. From the figure 4, it can be inferred that the proportion of long-distance (>5km) commuters is likely to increase with the increment of parameter λ_i. It is revealed by calculation that the value of *P* within 5 km is less than 0.5 when parameter is greater than 4.0. Therefore in consideration with the economy of bus service, the selection criteria for demand points is defined as below:

(1) The Population of census tracts>2000
(2) The parameter λ_i >4.0

After selecting the demand points in conformity with the above criteria, all the candidate stops then were identified (see figure16). So a preliminary commuting bus route was developed with a variety of ArcGIS techniques (Owing to the limitation of space, the detailed procedures are omitted). If the bus line can serve commuters with higher frequency and lower price, the possibility of car driving to work would be decreased as the result.

Given the commuting distance distribution with travel mode share in different distance bins, the current total energy use for a study region in terms of the one-way home-to-work journey can be calculated as bellows:

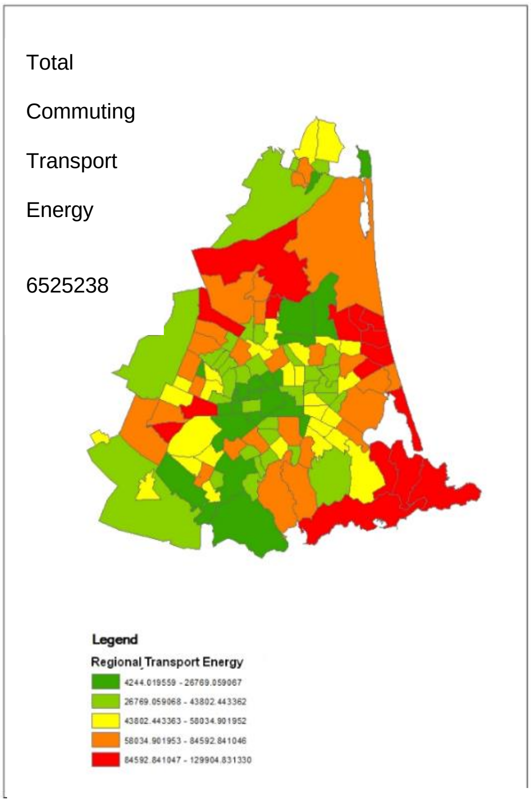
$$E_i = \sum_{j=0}^{n} e_m * d_{ij} \qquad (10)$$

Where e_m is the energy intensity of transportation tools((Newman & Kenworthy, 1999), d_{ij} is the distance to destination *j*, *n* is the number of employment facilities for origin *i*. The current regional Commuting Transport energy use for one-way work trips was calculated and mapped in figure 14. It can be seen that the major high energy consumption censuses are situated in suburb areas, which result from the large population or longer commuting distance.

Assuming those commuters who currently drive long distance to work could access to this bus service by walk, and commuters in short distances can ride a bike as the alternative means of travel to their workplaces, the consumption of transport energy should theoretically drop down.

- Mode=bike if d_{ij} <=5 km
- Mode=bus if d_{ij} >5km and in the vicinity of bus stops
- Mode=car if else

Recalculate the energy use with equation (10), the regional commuting energy use after mode shift was mapped in figure 15 and figure 16 respectively. At first glance, there is no much disparity in energy consumption distribution between figure 14 and figure 15, especially for the dark red areas. A reasonable explanation is that resident living in these suburb areas have relatively higher proportion of longer commuting distances, which makes it impossible to choose cycling as the travel mode. Nevertheless the total energy consumption still might be reduced 33% simply by mode shift into cycling. It can be seen from the figure 16 that the greened areas expand considerably compared to figure14 and figure 15, both regional transport energy use



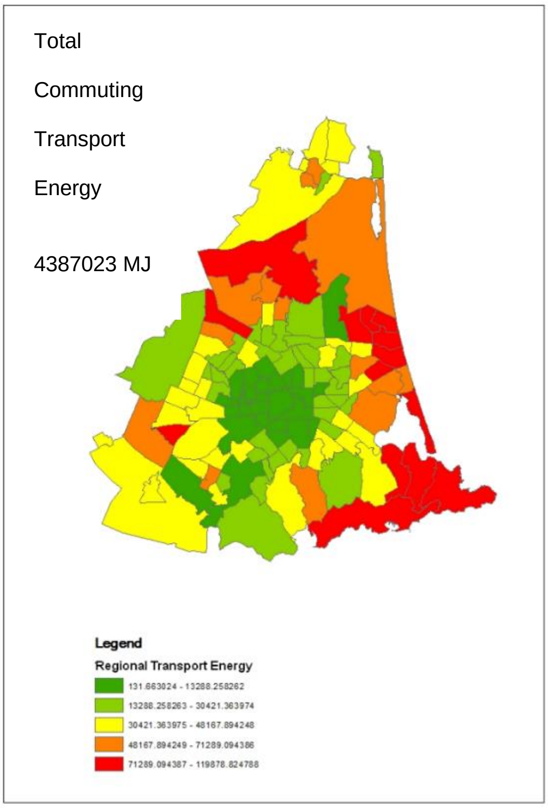
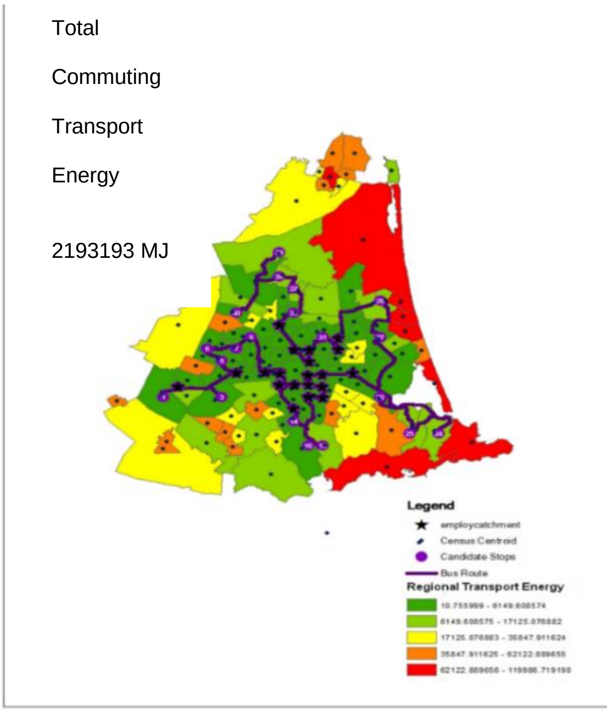


Figure 15. Transport energy distribution after mode shift to



Scenario	Maximum Energy Reduction
Mode shift to cycling	33%
Mode shift to cycling + bus	67%

Figure 16. Proposed commuting Bus line development and resulting transport **Energy distribution**

and total energy use are obviously improved by nearly 70 percent of reduction. Hence the low carbon potential of Christchurch development could be realized by mode shift only provided the improved cycling and transit infrastructure are available as well as favorable policies are implemented. In other words, the Christchurch city itself has good potentials to reduce carbon emissions from commuting with the urban form and land use remained constant, some minor adjustments in transport system of Christchurch may contribute to reduction in transport energy use.

Conclusion

This research studied the commute travel patterns in New Zealand with the intention to discover a universal law governing commuting distance distribution and investigating the determinants behind. Based on the training data from the commuter flows of sample census tracts, the fitting analysis demonstrate that the cumulative possibility distribution of commuting distance has an obvious regularity and the exponential function family can fit it well. In this paper, the Rayleigh function was employed to quantify the commuting distance distribution as it takes a simple form with only one coefficient to be determined, which to some extent facilitate the following regression analysis. Then the average distance to employment catchment, through the analysis to data pertinence, was specified as the single predictor variable to affect the value of parameter. Consequently a set of simultaneous equations in representative of commuting distribution were developed, for which only a few measurable factors are required including population, employment opportunity and geographical distribution of household and workplace. In order to validate the predictability of model, two types of data were analyzed: one is the validation for test data with nearly 80 percent of accuracy, the other one is a Monte Carlo simulation to approximate disaggregated commuting OD pairs by private car in comparison with the available VKT data. The results display little differences between the simulated commuting VKT data and the real data. Finally two applications of this model were presented to explore the low energy-intensity transport potentials of Christchurch city. If the land use and spatial structure of Christchurch remain unchanged, a 30% reduction of transport energy consumption may be achieved just by mode shift to cycling for work trips, and a highly efficient transit system could reduce up to 70 percent of current transport energy use. Under the circumstances where the requirement for precision is not that rigorous, this model has potential implications for evaluating the proportion of commuters in different distance bins and facilitating the analysis for urban resilience and adaptation to climate change or oil shortage.

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